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Volume 149

Contributions to Special IGY

Meeting 1959

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INTRODUCTION

The papers comprising this volume and presented either in full, or in summary, with a reference to publication elsewhere[1], were delivered before a Special Meeting of the International Council for the Exploration of the Sea in Copenhagen in the first days of October 1959, immediately before the Annual Meeting of that year[2]. They derived from the part played by the Council in sponsoring, under the leadership of Dr. *G. Böhnecke*, then Chairman of the Council's Hydrographical Committee, the North Atlantic Polar Front Survey as an integral part of the world-wide oceanographical programme of the International Geophysical Year[3].

The commission which was delegated to the Council and the International Commission for the North-west Atlantic Fisheries by the Oceanographic Committee of the Special Committee for the International Geophysical Year set up by the International Council of Scientific Unions, specified oceanographical, including marine biological investigations to be carried out in the appropriate regions. Endorsing the recommendation of its Hydrographical Committee, the Council thereupon proposed to its members that their IGY Polar Front investigations should be made in the spring (March $\pm$ one month) and the autumn (September $\pm$ one month) of 1958. In actual fact pertinent scientific voyages were undertaken by member countries of the Council and of the Commission throughout the entire International Geophysical Year, namely, from July 1957 to December 1958 inclusive. The above-mentioned Special Meeting, therefore, was designed to include all such investigations in at least preliminary aspect and insofar as time had permitted the examination of the data collected.

The cruises undertaken by the various ships of the countries concerned during the IGY period are represented on the three following chart-figures (Figures 1, 2, and 3), and their main objectives set out in the subjoined programmatic Table of the North Atlantic Polar Front Survey.

J. B. Tait

[1]) See C. Res. 1959/4; Proc.-Verb., I, 1959. Cons. int. Explor. Mer, 1960, p. 42.
[2]) See C. Res. 1958/9; Rapp., 46th Réunion Stat. Cons. int. Explor. Mer., 1959, p. 23.
[3]) See the Report of the IGY Sub-Committee of the Hydrographical Committee, C.M. 1957.

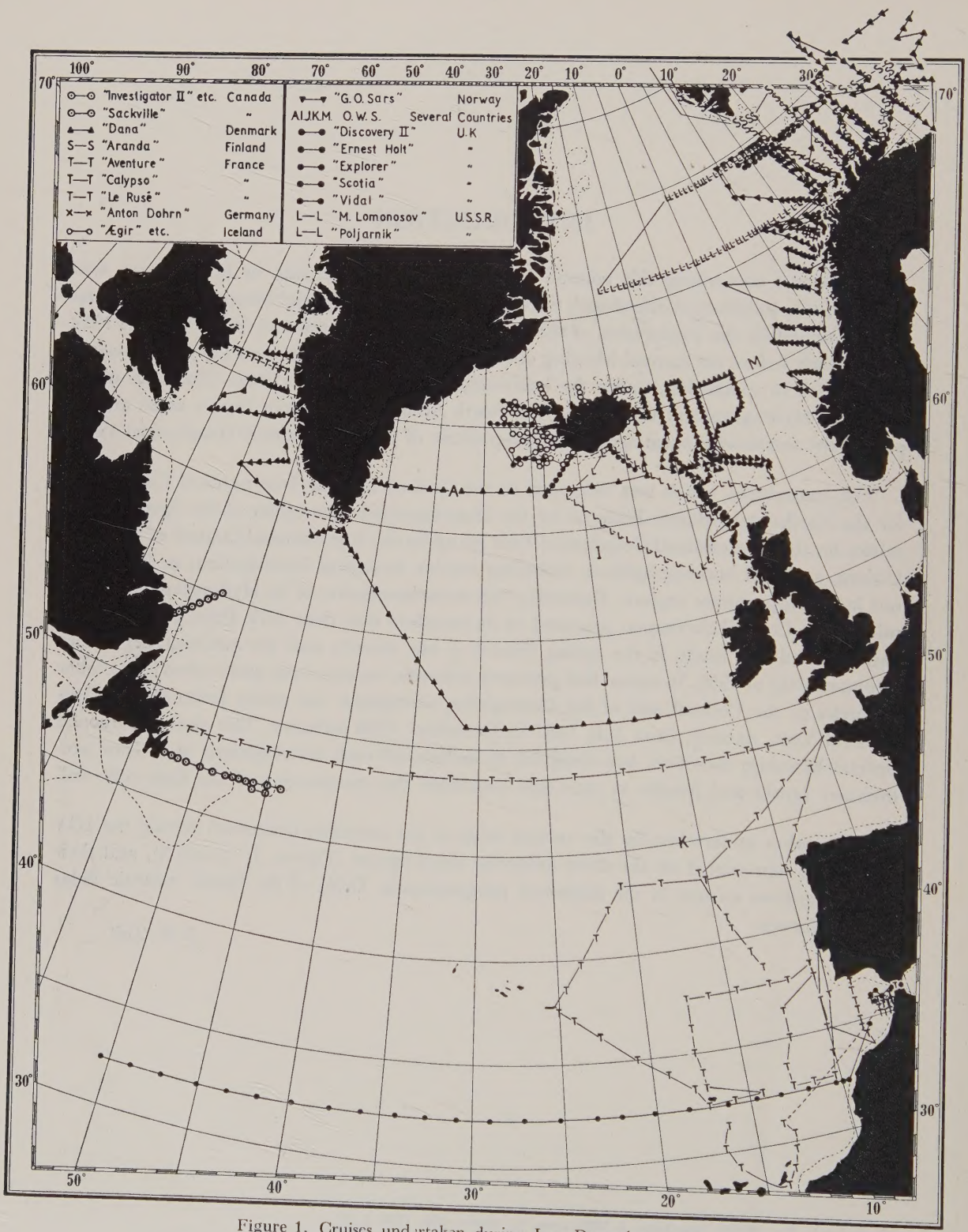

Figure 1. Cruises undertaken during June-December, 1957.
(Surface observations and BT stations have not been entered on this chart.)

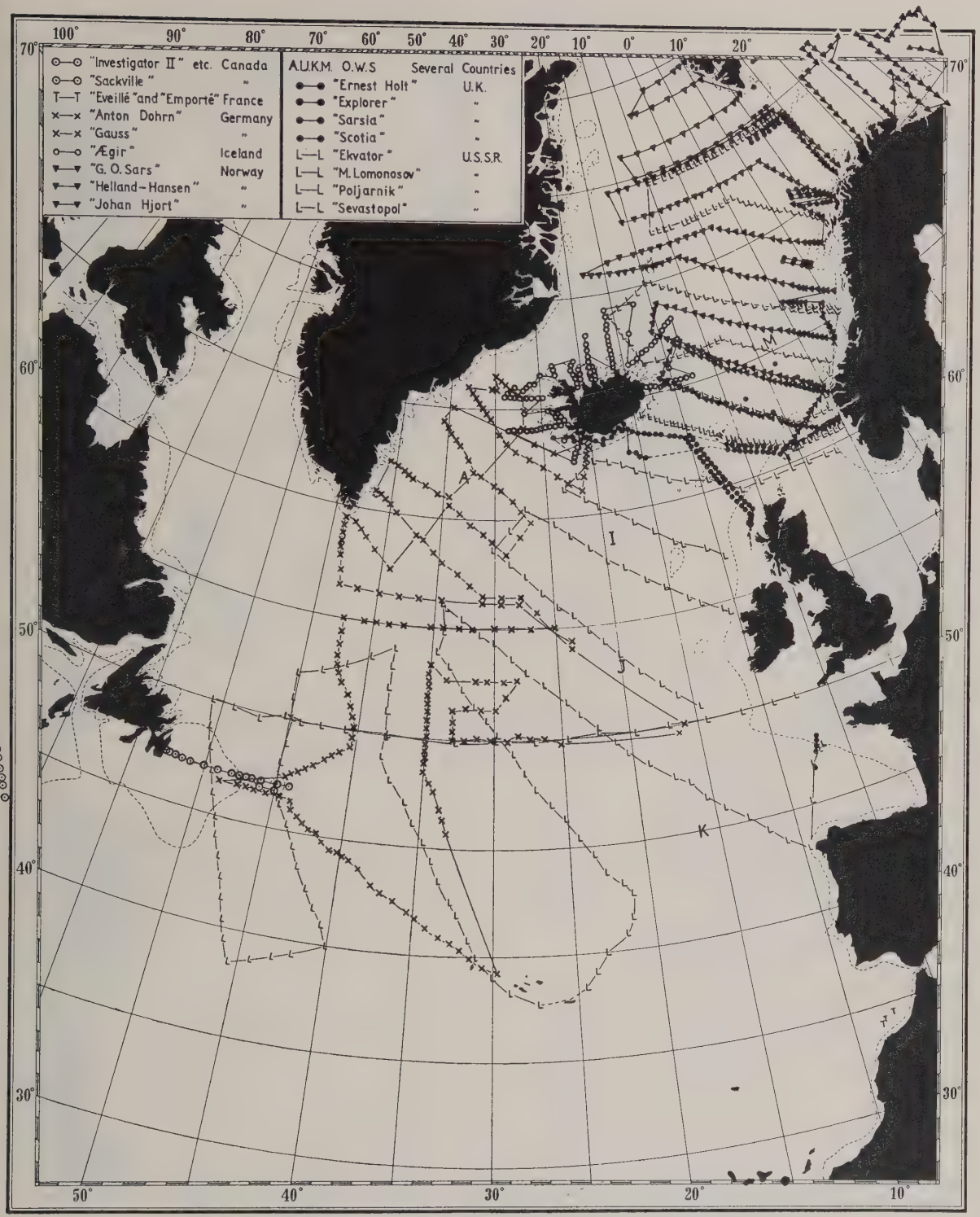

Figure 2. Cruises undertaken during January-June, 1958.
(Surface observations and BT stations have not been entered on this chart.)

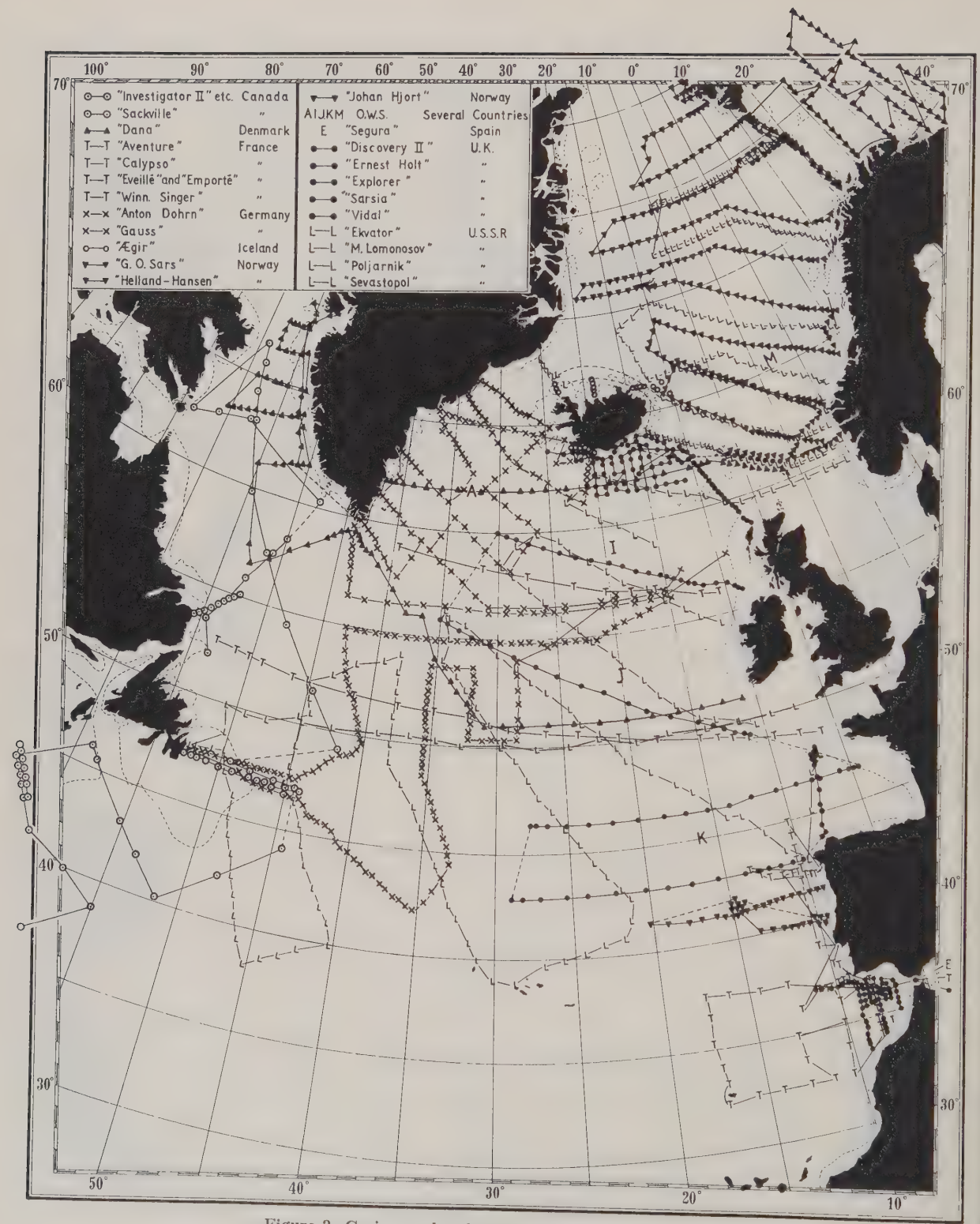

Figure 3. Cruises undertaken during Juli-December, 1958.
(Surface observations and BT stations have not been entered on this chart.)

North Atlantic Polar Front Survey 1957–58

Programmatic Table

(Compiled by the Service Hydrographique of the ICES)

Canada				
"Sackville" and "Fort Frances"	Section over the Scotian Shelf off Halifax	June 1957 April 1958 May 1958 Aug. 1958 Oct. 1958	7 oceanographic stations	Temperature, salinity, and at times oxygen and phosphate
also "Investigator II" and "A. T. Cameron"	Section over the Grand Banks from St. John's to Flemish Cap	July 1957 Mar. 1958 July 1958 Oct. 1958	11 oceanographic Stations	As above
	Section over the Labrador Shelf to Seal Island	Aug. 1957 Aug. 1958	8 oceanographic stations	Temperature and salinity
"Sackville"	Sections over the region: Bermuda–Davis Strait	22/7–9/9 1958	49 oceanographic stations	Temperature, salinity, oxygen, silicate, phosphate, and nitrite Plankton
Denmark				
"Dana"	North of the Faroes. Section: Faroes–Greenland along 62° N	3–28/6 1957 28/6–3/7 1957	Oceanographic stations	Temperature, salinity, oxygen (in the deep layers), phosphate (in the upper layer) Plankton
	5 sections off West Greenland	July 1957	Oceanographic stations	As above
	Section Cape Farewell–Ireland	9–18/8 1957	Oceanographic stations	As above
	Sections: Shetland–Faroes, and Faroes–East Greenland along 62° N	30/6–1/7, 3–10/7 1958	Oceanographic stations	As above
	6 sections off West Greenland	17/7–15/8 1958	Oceanographic stations	As above
	Section Cape Farewell–Ireland	15–25/8 1958	Oceanographic stations	As above
England				
"Ernest Holt"	Norwegian Sea and Barents Sea: sections between Shetland Islands and Svalbard	May 1957 to December 1958	9 oceanographic sections (167 stations)	On passage: surface temperatures by thermograph; surface currents by towed electrodes (GEK) Observations on stations at international standard depths; temperature and salinity always, chloride-sulphate ratio and alkalinity occasionally Observations at deep-moored buoys: currents
"Discovery II"	North Atlantic, Cross-sections in 24° N and 32° N	6/10–7/12 1957	Oceanographic stations	Observations on stations: temperature, salinity and oxygen Plankton net hauls and ^{14}C estimations Deep currents
	32°–33° N, 75°–76° W	Summer 1958	Oceanographic stations	Deep currents
	400 miles west of Oporto	July 1958	Oceanographic stations	Deep currents
	West of Ireland to the Mid-Atlantic Ridge and	18/8–23/9 1958	110 oceanographic stations	Observations on stations: temperature, salinity, oxygen, phosphate, and silicate
	Western Approaches to the Straits of Gibraltar	7–21/11 1958	Oceanographic stations	Deep currents

"Sarsia"	Bay of Biscay	March, April and September 1958	Oceanographic stations	Observations on stations: temperature, salinity, oxygen, silicate, phosphate, vitamin B_{12}, copper, cadmium, uraniu Deep flagellates Deep water masses Internal waves Currents at the continental edge
Ocean Weather Ships	North Atlantic. Stations A, I, J and K	Throughout 1957 and 1958	Surface observations	On stations and on passage: temperature an salinity
"Vidal"	Straits of Gibraltar	22/10 1957	6 stations	Temperature, salinity; soundings BT observations
		26–27/10 1958	3 stations	Temperature, salinity; soundings Plankton
Finland				
"Aranda"	Barents Sea and north of Spitsbergen	1–27/7 1957	8 oceanographic sections (55 stations)	Hydrographic observations: temperature, salinity, oxygen, and pH at all observatio depths at all stations. At every second dept on 52 stations: alkalinity, PO_4, SiO_2, NH NO_3, and NO_2 CO_2-determinations in 51 air and 46 surfac water samples Geological bottom samples and stratigraph studies Gravity measurements at 21 points at se Plankton samples by vertical plankton hau
France				
"Président Théodore Tissier"	Celtic Sea	20/4–5/5 1958	81 oceanographic stations	Temperature and salinity
"Aventure"	Davis Strait	21–23/8,	9 stations	Temperature and salinity
	Section Newfoundland–Brest	11–22/10, 1957	22 stations	Soundings
	Section Scotland–Greenland	28/8–3/9 1958	10 stations	Drift-cards
	Section Labrador–Brest	14–24/10 1958	21 stations	As above and BT observations
	Northern North Atlantic	12/3–22/10 1957 20/3–24/10 1958	Surface observations	Temperature and salinity
"Amiral Mouchez"	Western Approaches to the Straits of Gibraltar	18–20/4 1958	5 oceanographic stations	Temperature and salinity Drift-cards
	Brest–Gibraltar	2–5/10 1957 10–20/4 1958	Surface observations	Temperature and salinity
"Calypso"	Western Approaches to the Straits of Gibraltar	19/7–28/9 1957	58 stations	Temperature and salinity; soundings BT measurements Surface current (GEK); swell
	33° N–45° N, 8° W–18° W	6/7–20/8 1958	56 oceanographic stations	As above
	At the position 42°34′ N, 10°24′ W	19–21/7 1958		Measurement of current in the surface and at 1,000 m depth level
"Winnaretta Singer"	Straits of Gibraltar	7–21/8 1958	9 anchor stations (on 2 sections) worked during a period of semidiurnal tide	At each station 3 to 5 series of temperatu and salinity observations and of current measurements at the surface and at the bottom
"Le Passeur du Printemps"	Straits of Gibraltar	21/7–25/8 1957	30 stations	Temperature, salinity, oxygen, nitrogen, phosphate; BT observations
		8–20/8 1958	25 stations	Temperature, salinity, oxygen Currents

"Le Rusé"	Coast of Morocco Straits of Gibraltar	23–29/8 1957 23–26/11 1957	19 stations 16 stations	Temperature, salinity BT observations
"Eveillé" "Emporté"	Off Casablanca	Feb.–Oct. 1958	9 stations	Temperature and salinity
"Voltigeur"	Coast of Morocco	25/9–3/10 1958	26 hydrographic stations	As above
"Mermoz" and "Le Verrier"	Ocean Weather Station A	Aug.–Oct. 1957 Mar.–June 1958	Oceanographic stations and surface observations on passage and on station	Temperature and salinity
	Ocean Weather Station J	July–Sept. 1957 Jan.–Mar. 1958 Dec. 1958		
	Ocean Weather Station K	June–July 1957 Oct. 1957 Feb. 1958 May–Dec. 1958		
"Croix de la Lorraine"	Celtic Sea	6–9/8 1957	Surface observations	Temperature and salinity
"Agile"	Celtic Sea	18/3–10/4 1958	Surface observations	As above
"Agenais"	Newfoundland–Greenland	22/1–20/2 1958	Surface observations	As above
"La Bourdonnais"	Newfoundland–Greenland	23/1–17/2 1958	Surface observations	BT observations
"Le Bernais"	Newfoundland–Greenland	30/9–10/10 1958	Surface observations	Temperature and salinity
"L'Alsacien"	Newfoundland–Greenland	9–16/7 1958	Surface observations	As above and Drift-cards
"Ailette"	North-east Atlantic	11/3–1/8 1957	Surface observations	Temperature and salinity
"Jeanne d'Arc"	Western Approaches to Gibraltar	29/10–1/11 1957	Surface observations	As above
	North Atlantic	19–22/4 1958 30/5–2/6 1958 20–26/11 1958	Surface observations	As above
Germany				
"Anton Dohrn"	North Atlantic 69° N–70° N 15° E–17° E	23/11–2/12 1957	78 oceanographic stations	Observations of temperature and salinity, currents, internal waves
"Gauss"	North Atlantic 38° N–56° N 10° E–46° W	6/3–7/5 1958	Oceanographic sections (107 stations)	Hydrographic investigations: depths by echo-sounders; surface temperatures and air temperatures by thermographs; surface currents by towed electrodes (GEK); turbidity in 4 m depth by transparency meters Observations on stations at international standard depths: temperature, salinity, oxygen; fluorescence
		29/7–25/9 1958	(154 stations)	Biological investigations: samples were taken for determination of organic production, content of organic carbon; composition of microplankton; step-catches of plankton in the upper layers Meteorological observations

"Anton Dohrn"	North Atlantic 50° N–66° N 1° E–43° W	27/2–22/4 1958	(123 stations)	Same observations as with VFS "Gauss" Other biological observations: investigations of the bottom bacteria in the deep-sea by core samplers, of the bottom fauna by bottom samplers, of the fishes on the shelves by trawl nets
		4/8–27/9 1958	(172 stations)	
Iceland				
"Ægir" and "María Júlía"	N coast of Iceland	26/7–10/8, 26/8 1957	3 oceanographic sections	
"Ægir"	W coast as far north as the Iceland–Greenland Ridge	11/11–1/12 1957	(29 stations)	Temperature, salinity, and oxygen BT measurements
	W, N, and NE coast	19/5–18/6,	(117 stations)	
	N and NE coast	4–11/8,	(12 stations)	
	NE coast	11–14/11,	(5 stations)	
	SW coast	19–20/12 1958	(21 stations)	
Netherlands				
"Cirrus" "Cumulus"	Ocean Weather Stations A, I, J, K, and M	July 1957–Dec. 1958	Surface observations	Temperature and salinity on passage to and from station and on station BT observations on passage and on station
"Cirrus"	Ocean Weather Station I	Oct. 1957 and Apr.–May 1958	Oceanographic stations	Temperature, salinity, and oxygen BT observations
	Ocean Weather Station K	Feb.–Mar. 1958		
"Cumulus"	Ocean Weather Station M	June–Nov. 1958		
Norway				
"Suløy" "Achilles"	Across Holsteinsborg Deep (W. Greenland)	19/8, 23/8 1957	2 sections	BT measurements
"Achilles"	Westwards from the W. Greenland banks	24–25/8 1957	3 sections	
"G. O. Sars"	Norwegian Sea and Barents Sea	8/7–28/8,	(abt. 280 stations)	Temperature and salinity
		17/9–2/11 1957	(abt. 95 stations)	Echo-soundings BT measurements
"G. O. Sars" "Johan Hjort"	Norwegian Sea between Shetland and Svalbard: Western limit: ice border of East Greenland coast and a line 71° N, 18° W–Faroe Islands; Eastern limit: coast of Norway and Svalbard; Barents Sea to 75° N and 45° E	31/3–24/6 1958	46 oceanographic sections (421 stations) (425 BT stations)	Temperature, salinity, oxygen, and phosphate Current measurements at 3 anchor stations Echo-sounders and asdic operated continuously Plankton and organic production
"Johan Hjort"		27/8–15/10 1958	(abt. 260 stations) (abt. 75 BT stations)	
"G. O. Sars"	Barents Sea	26/9–27/10	(92 stations)	Temperature, salinity, oxygen, and phosphate Echo-soundings
	Faroe-Shetland Channel	15–16/12 1958	(8 stations)	
"Helland-Hansen"	Norwegian Sea	13–22/3 1958	(71 stations)	Temperature, salinity, and oxygen Echo-soundings
		17–26/10 1958	(63 stations)	
	400 miles west of Oporto	18/6–13/7 1958	(73 stations)	As immediately above and deep currents
"Polarfront I" "Polarfront II"	Ocean Weather Stations M or A	Throughout 1957–1958	Surface observations and 6 stations per week	Temperature and salinity BT observations on passage and on station

Scotland				
"Scotia"	Faroe-Shetland Channel Iceland-Faroe Ridge	14–30/6 1957	Hydrography Plankton Demersal Trawling	Temperature, salinity, oxygen, phosphate; drift bottles
	Faroe-Shetland Channel	4–6, 19–20/9 1957	Hydrography Plankton	As above
	Faroe-Shetland Channel	2–4, 18–19/6 1958	Hydrography Plankton	As above
"Explorer"	S and W of Iceland	9–20/9 1957	Hydrography Plankton Demersal Trawling	As above
	Faroe-Shetland Channel	29/11–1/12 1957	Hydrography Plankton	As above
	As above and Iceland-Faroe Ridge and S of Iceland	16/3–14/4 1958	Hydrography Plankton Demersal Trawling	As above
	S of Iceland	10–22/7 1958	Hydrography Productivity Plankton Trawling	Temperature, salinity, oxygen, phosphate, chlorophyll, ^{14}C; drift bottles
	SE of Iceland Iceland-Faroe Ridge	31/7–4/8 1958	Hydrography Productivity Plankton	As immediately above
	Faroe-Shetland Channel Iceland-Faroe Ridge	16–26/9 1958	Hydrography Plankton	Temperature, salinity, oxygen, phosphate; drift bottles
Spain				
"Segura"	Straits of Gibraltar	7–23/8 1958	1 section	Temperature and salinity
USSR				
"Lomonosov"	North-eastern part of the Atlantic between Hebrides–Shetland Islands and Iceland	11/11–1/12 1957	2 oceanographic sections (50 stations)	1. Hydrological observations at standard levels: temperature, salinity, state of sea, transparency, and colour 2. Standard meteorological observations at fixed hours 3. Actinometrical observations 4. Hydrochemical observations: O_2, pH, NO_2–N, CO_2, P, Si 5. Depth measuring and collecting of bottom samples 6. Plankton (24 samples)
	Central part of the North Atlantic	2/3–4/6 1958	Oceanographic sections (142 stations)	As 1, 2 and 4 above 3. As 3 above and aerological observations 5. Depth measuring and determination of the nature of bottom
	As above	11/10–10/12 1958	(122 stations)	As 1, 2, 3 and 5 immediately above 4. Hydrochemical observations 6. Plankton
"Ekvator"	North-eastern part of the North Atlantic	28/3–11/4 1958	Oceanographic sections (27 stations)	1. Hydrological observations at standard levels: temperature, salinity, state of sea, transparency, and colour 2. Standard meteorological observations at fixed hours 3. Measuring of current on stat. Nos. 54, 64, 67, 69, 71, and 77 4. Hydrochemical observations: O_2, pH 5. Depth measuring and determination of the nature of bottom 6. Plankton

"Ekvator"	North-eastern part of the north Atlantic	5–28/10 1958	(52 stations)	As 1, 2, 5, and 6 on page 15 3. Measuring of current on stat. Nos. 15 153, 168, 172, and 174 4. Hydrochemical observations: O_2
"Poljarnik"	Southern part of the Greenland Sea and adjacent part of the Norwegian Sea	18/7–9/8 1957	Oceanographic sections (68 stations)	1. Hydrological observations: temperatur and salinity; BT observations 2. Standard meteorological observations fixed hours
	As above	20/3–10/4 1958	(57 stations)	1. Observations of temperature and salin at standard levels from surface to 1,000 m depth; BT observations to 200 m 2. As 2 above 3. Hydrochemical observations: O_2 and phosphate 4. Plankton at 27 stations
	As above	30/9–27/10 1958	(59 stations)	1. Observations of temperature and salin at standard levels from surface to 2,000 m depth 2. As 2 above 3. Observations of O_2 4. Plankton
"Sevastopol"	Southern part of the Norwegian Sea	25/3–25/4 1958	Oceanographic sections (132 stations)	1. Observations of temperature and salini at standard levels 2. Standard meteorological observations fixed hours 3. Actinometric and aerological observatio
	As above and Denmark Strait	25/9–26/10 1958	(114 stations)	4. Hydrochemical observations: O_2, pH, phosphate, silicate, nitrite, alkalinit redoxpotential, ammonia, nitrate, a nitrogen 5. Determination of the nature of botto and echo-soundings 6. Zoo- and phytoplankton

1.

Hydrographic Results of the "Aranda" Expedition to the Barents Sea in July 1957

By

Ilmo Hela

Institute of Marine Research, Helsinki, Finland

Summary*)

This is a report on the hydrographic work carried out by the "Aranda" Expedition in the period June to August 1957 to the Barents Sea and to Northeastland. The course of the cruise (Fig. 1) was determined by the interests of:—

(i) the hydrographers wishing to run sections perpendicular to the main currents,

(ii) the students of bottom stratigraphy wanting to get piston core samples and two-frequency echo recordings from the deepest basins, especially from the eastern basin of the Barents Sea, where the Soviet oceanographers had observed recent sedimentation of iron and manganese,

(iii) the students of gravity anomalies wanting to perform their measurements on all the shallow banks,

(iv) the air chemists who were anxious to occupy, among other, the same stations as Buch (1939) in 1936, and

(v) the Swedish-Finnish-Swiss Northeastland Expedition which was to be transported to Murchison Bay. This additional task of transporting the said team as early as possible at the beginning of the IGY from Longyearbyen to Northeastland and, along with them, equipment and material from Scandinavian ports, made it impossible for us to postpone our cruise to the later, synoptic periods.

The hydrographic and chemical routine determinations and similar data have been published already by Hela and Koroleff (1958). In the main the routine methods were followed. In order to determine the positions of the stations as accurately as possible, our gravity specialist, Dr. Tauno Honkasalo, an astronomer as well, made use of the sun every single time, day or night, when we were able to see it through the clouds or fog. He performed the computations more accurately than is normally done in these waters by means of the routine guides. The wind was measured regularly and the effect of current estimated for navigational purposes, in waters shallower than 150 metres, by means of the drift of the vessel in relation to anchored buoys.

The main part of our hydrographic programme in the Barents Sea consisted of the following hydrographic sections, which will be described briefly. (The exaggeration of the depths in the following figures is 500-fold.) It is hoped that these data consisting of more numerous chemical determinations than is normal in these waters, will make a useful addition to the routine results of English, Norwegian, and Soviet investigations in the same waters.

(1) Sörkapp/Bear Island/Finnmark (Ingöya), (St. 34—22), with the longitude range between 16°45′E and 23°56′E, the mean longitude being 20°20′E: 9.—12. July.

(2) Hopen/Finnmark (Nordkapp), (St. 45—55), along longitude 25°E: 24.—26. July.

(3) Central Bank (74°31′N, 32°27′E) / Finnmark (Slettnes, 71°11′N, 27°10′E), (St. 14—21): 5.—7. July.

(4) Eastern Basin (72°56′N, 41°50′E) / Finnmark (Vardö, 70°26′N, 31°19′E), (St. 9—1): 1.—3. July.

(5) Sörkapp (76°22′N, 16°45′E) / Eastern Basin (72°56′N, 41°50′E), (St. 41—44, 47, 15, 13—9): 3.—4., 5., 23., and 25. July.

The sections (1) and (2) are more or less perpendicular to all the currents and their branches flowing between Spitsbergen and Finnmark, namely:—

The East Spitsbergen Current,
The eastwards flowing branch of the West Spitsbergen Current penetrating the Storfjordrenna,
The Bear Island Current,
The north-eastward flowing branch of the North Cape Current following the Bear Island Channel, and
The North Cape Current.

*) The full paper will appear in *Commentationes Physico-Mathematicae* of the Societas Scientiarum Fennica.

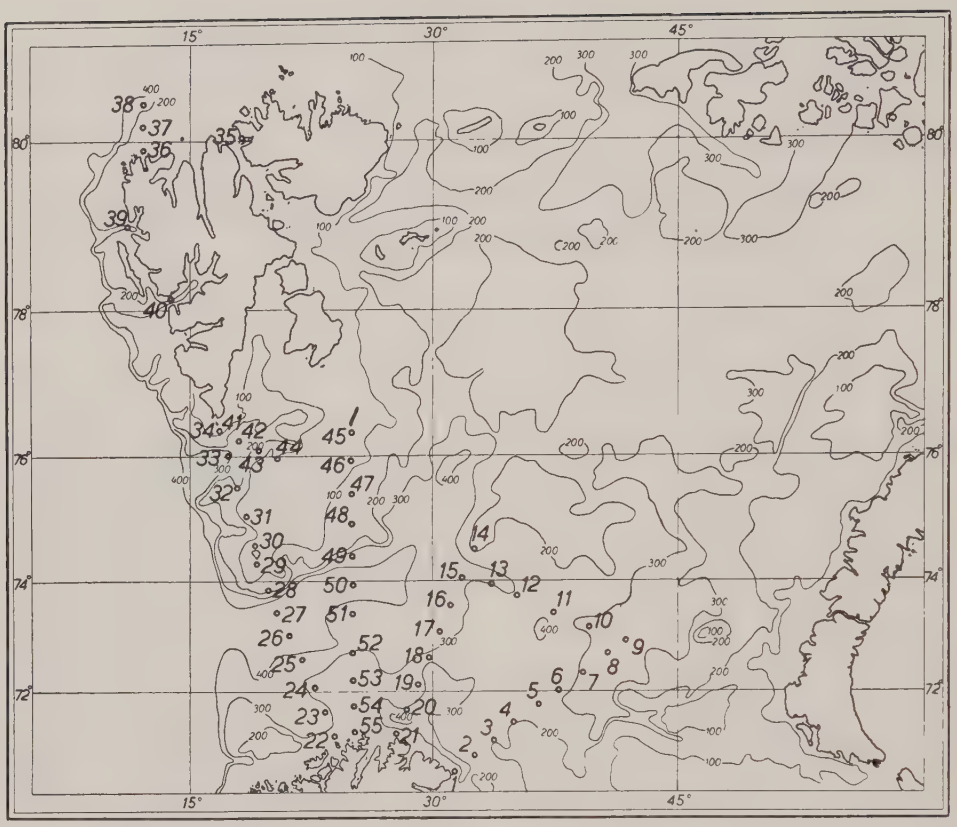

Figure 1. Positions of the sections worked by the R/V "Aranda" in 1957.

Section (3) similarly crosses the North Cape (or Murman) Current and also its north-eastward branch which follows the direction of the Bear Island Channel. Section (4) crosses, of course, the Murman Current and an eastern, southbound branch of the Bear Island Current but not the north-eastward branch of the North Cape Current. Finally, the incomplete NW/SE section (5) crosses the East Spitsbergen Current, the warm eastward branch of the West Spitsbergen Current penetrating the Storfjordrenna, the Bear Island Current, the north-eastward branch of the North Cape Current following the Bear Island Channel, and the eastern branch of the Bear Island Current.

These sections can be compared with other analogous results. In this brief summary only sporadic reference will be made to the results of the "Poseidon" Expedition of 1927 (Schulz, 1929; Hansen, 1935) and to the mean surface charts of Krauss (1957) on one hand, and to some of the recent results published by Hill (1958, 1959), Lee (1957, 1959), and Midttun (1959) on the other hand.

1. Section Sörkapp/Finnmark

(a) *Temperatures* (Fig. 2). The temperature presensations of Figures 2, 5, 7, 9, and 11 are based on the hydrographic stations, together with 150 BT stations. The geometric dimensions of the North Cape Current seem relatively normal for recent years. The polar front, only some 70 km south of Bear Island, is steep (1: 60, corresponding to a speed difference of 45 cm/sec.). Along the Storfjordrenna another tongue of the Atlantic Water penetrates towards the Spitsbergen Shelf. Along the southern slope of Sörkapp, Deep Water of the North Polar Sea flows towards the west as the East Spitsbergen Current. The secondary polar front between these two waters is unstable, as can be seen from the complicated vertical distribution of temperature (Fig. 3). Here the speed difference must be about 50 cm/sec.

(b) *Salinities* (Fig. 4). The southern limit of the purest Atlantic Water against the Coastal Water is seen clearly. The maximum salinity in this water was 35·13 ‰ (in 1927 it was 35·14 ‰). However, the significant difference is the following: in 1957 the

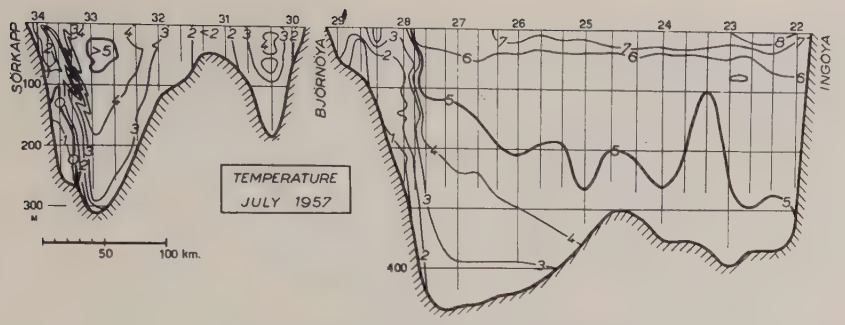

Figure 2. Temperature distribution on the Sörkapp/Bear Island/ Finnmark (Ingöya) section: 9.–12. July 1957.

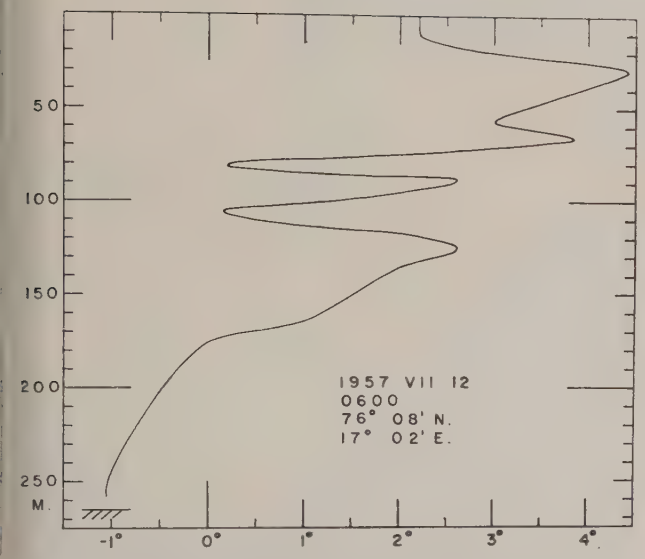

Figure 3. Vertical distribution of temperature through the polar front surface south of Sörkapp: 12. July 1957.

width of the area with water more saline than 35 ‰ at the surface was not less than 135 km while in 1927 the same isohaline followed the depth of 75 m and the surface salinities were only some 34·6 ‰. The minor tongue of Atlantic Water, between Spitsbergen and Bear Island, similarly shows larger dimensions and even higher maximum salinities, namely, 35·12 ‰ as against 34·97 ‰ in 1927. In 1956 this tongue (Hill, 1958) was still stronger and more saline.

2. Section Hopen/Finnmark

(a) *Temperatures* (Fig. 5). The polar front south of Hopen is in this representation only about 1: 550 steep, because of the small angle between the section and the Bear Island Current. The minimum temperature of the Deep Water of the North Polar Sea is −1·4°C. On the North Cape Bank the bottom temperatures are some 4·5°, in the Bear Island Channel between 2° and 3° C.

(b) *Salinities* (Fig. 6). Maximum salinity observed is 35·14 ‰ (St. 52, at 122 m depth); in 1927 it was only 35·07 ‰. The geometric dimensions of the core of the saline water are large. In March and October 1958 salinities higher than 35·1 ‰ were observed.

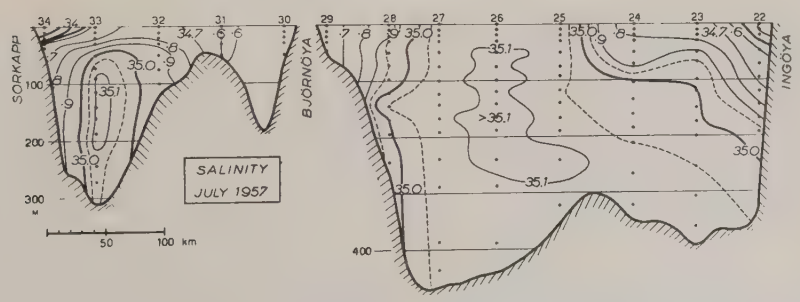

Figure 4. Salinity distribution on the Sörkapp/Bear Island/ Finnmark (Ingöya) section: 9.–12. July 1957.

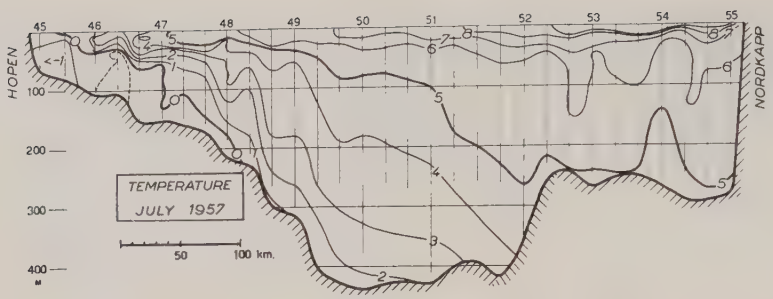

Figure 5. Temperature distribution on the Hopen/Finnmark (Nordkapp) section: 24.–26. July 1957.

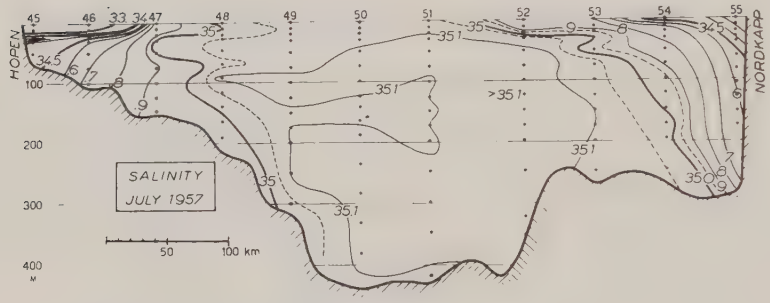

Figure 6. Salinity distribution on the Hopen/Finnmark (Nordkapp) section: 24.–26. July 1957.

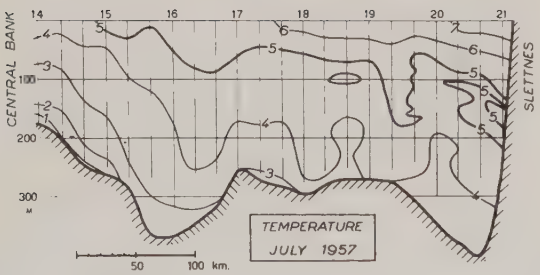

Figure 7. Temperature distribution on the Central Bank/Finnmark (Slettnes) section: 7. July 1957.

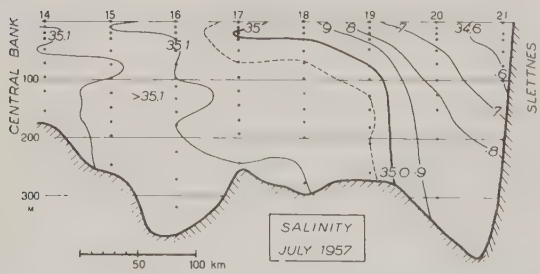

Figure 8. Salinity distribution on the Central Bank/Finnmark (Slettnes) section: 7. July 1957.

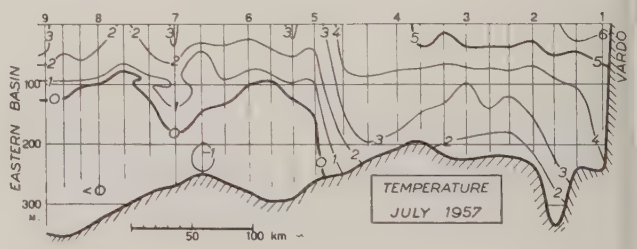

Figure 9. Temperature distribution on the Eastern Basin/Finnmark (Vardö) section: 1.–3. July 1957.

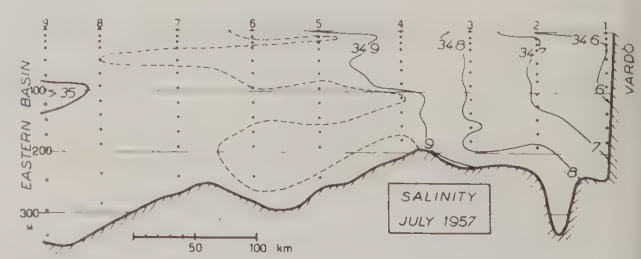

Figure 10. Salinity distribution on the Eastern Basin/Finnmark (Vardö) sections: 1.–3. July 1957.

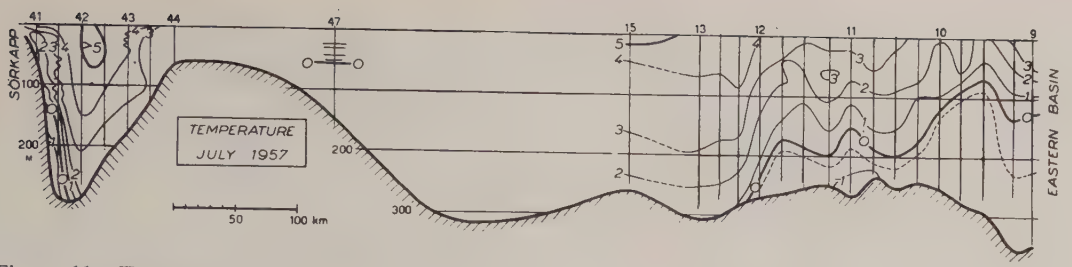

Figure 11. Temperature distribution on the Sörkapp/Eastern Basin section: 3.–4., 5., 23., and 25. July 1957.

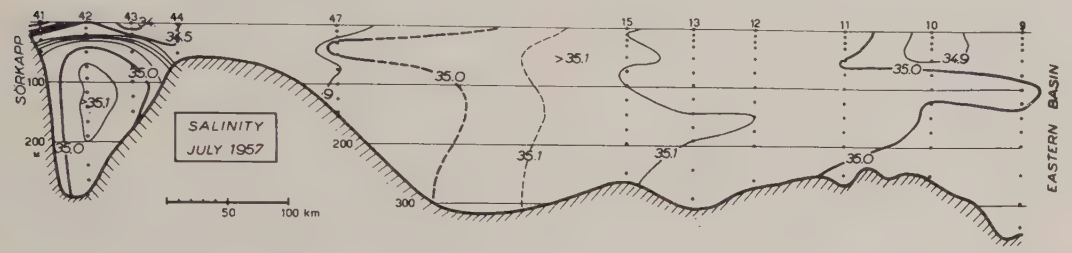

Figure 12. Salinity distribution on the Sörkapp/Eastern Basin section: 3.–4., 5., 23., and 25. July 1957.

3. Section Central Bank/Finnmark

(a) *Temperatures* (Fig. 7). The cores of the Deep Water branches of the North Polar Sea do not reach this section.

(b) *Salinities* (Fig. 8). Maximum salinities at stations 15 and 16 are 35·13 ‰, at the depths of 173 and 133 metres, respectively (in 1927: 35·06 ‰). Even at the surface the salinity 35·11 ‰ is observed.

4. Section Eastern Basin/Finnmark

(a) *Temperatures* (Fig. 9). Here the polar front between the Murman Current and the cold Deep Water is observed at depths below 100 metres, with a maximum slope of some 1:100. That branch of the North Cape Current which follows the Bear Island Channel is not observed here.

(b) *Salinities* (Fig. 10). The rather high salinities of the cold Deep Water are observed in this section also.

5. Section Sörkapp/Eastern Basin

(a) *Temperatures* (Fig. 11). Starting from the west, the East Spitsbergen Current is observed. Then the minor tongue of Atlantic Water penetrating the Barents Sea between Sörkapp and Bear Island along the Storfjordrenna crosses this section. The same cold water (St. 47) as in the East Spitsbergen Current flows along the south-eastern edge of the Spitsbergen Shelf. One branch of the North Cape Current follows the Bear Island Channel. On the Central Bank and in the Eastern Basin the cold Deep Water is encountered again. The polar front is crossed four times: between stations 41 and 42 from cold to warm, west of station 47 from warm to cold, east of station 47 from cold to warm, and at station 12 from warm to cold. Only the first two crossings appear as a polar front on the sea surface.

(b) *Salinities* (Fig. 12). The maximum salinity of the minor tongue of the Atlantic Water south-east of Sörkapp is 35·13 ‰.

The Barents Sea is characterized by strong mixing processes (cf. Fig. 3) and coastal (plus glacier) influences. Thus the significance of the T-S diagrams (Fig. 13) is somewhat limited. Nevertheless, without some characteristic water types it would have been difficult to describe the water movements. A complete T-S diagram for the area of our study leads to the following water masses:—

(i) *Atlantic Water.* (Mosby, 1938: "We may regard these extreme values, 5·04°C, 35·14 ‰, as the characteristic of the extreme Spitsbergen Atlantic Water". — Sverdrup, 1942: "The waters . . . have a high salinity and a high temperature, the maximum salinity decreasing from about 35·3 ‰ north of Scotland to about 35·0 ‰ off Spitsbergen and the subsurface temperature decreasing from about 8° to less than 4° in the same distance".)

(ii) *Deep Water of the North Polar Sea.* (Mosby, 1938: —1·00°C, 34·92 ‰. — Sverdrup, 1942: —0·85°C, 34·93 ‰.)

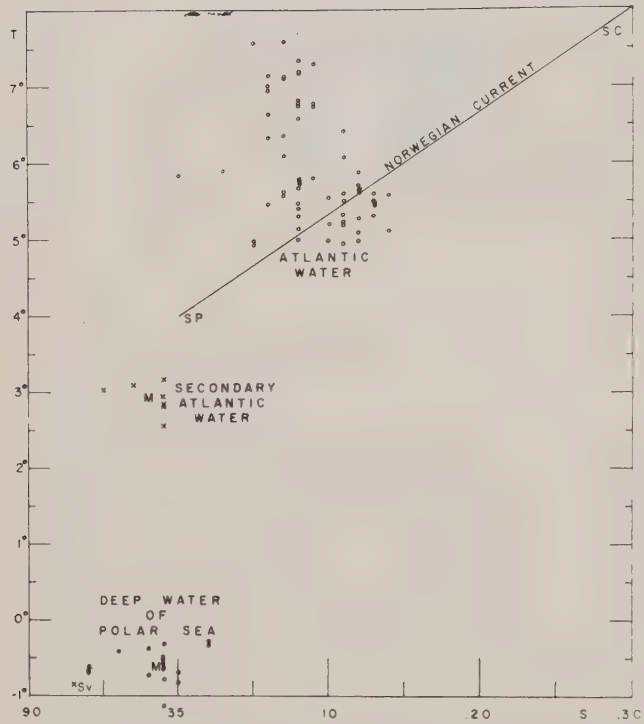

Figure 13. T-S diagram of the Barents Sea waters.

(iii) *Secondary Atlantic Water,* being Atlantic Water which has taken part in the circulation of the Barents Sea and partly changed its original characteristics owing to mixing with other waters. (Sverdrup, 1942: "The different basins ... contain waters of sligthly differing characteristics ...".) Our data seem to indicate that 2·94°C and 34·98 ‰ would be one reasonable combination of characteristics for this water mass of varying quality in our area.

(iv) *Coastal Water,* being originally mainly Atlantic Water but with a strong coastal influence.

(v) *Glacier affected Surface Water,* with a rather low salinity and low temperatures.

(vi) (*Surface Water of the North Polar Sea* can be excluded from our limited area of study.)

From all the T-S curves the parts of sections were selected which represented the pure water masses (i) and (ii). Then percentage limits were given to the cores of the different water masses. The schematic T-S diagram (Fig. 13) contains data for the cores only. The dots representing the core of the Atlantic Water appear quite scattered, since the surface waters were obviously affected by the summer radiation. Actually, all the deepest samples are slightly below the line of Sverdrup (cited above), indicating a possible increase in salinity of 0·03 or 0·04 ‰. If it is assumed that the Secondary Atlantic Water follows the same line of dilution-cooling, its mean salinity is 0·055‰ higher than expected. Finally, the corresponding mean characteristics for the Deep Water of the North Polar Sea are −0·60°C and 34·985 ‰, which indicates an increase in temperature of 0·40° (or 0·25°) and in salinity of 0·065 ‰ (or 0·055 ‰). However, a part of these differences must be due to the normal mixing processes. Therefore, after elimination of their probable effect, an increase in salinity of some 0·035 ‰ is left. Summarizing, an increase in salinity in all the basic water masses of 0·04 ‰ was observed. Fluctuations of this magnitude cannot be unusual for the water mass characteristics in the Barents Sea.

The reality of the water masses (i), (ii), and (iii) can be checked by means of the pH-O_2 diagram (Fig. 14). Mosby (1938) gave for this relationship (for Svalbard waters in general) the equation: $|pH| = 0{\cdot}101 \times |O_2| + 7{\cdot}36$. Our corresponding relationship, but for the Atlantic Water alone, is $|pH| = 0{\cdot}142 \times |O_2| + 7{\cdot}213$. Another reason for this and other discrepancies may be sought, as pointed out by Mosby, in the (lower) accuracy of the determinations of pH (due to the older methods). Our pH and other hydrographic data were published by Koroleff and myself (1958). Unfortunately, owing to an error in the signs of the formula of Buch (1945) for the computation of pH, all pH data in our publication are slightly out. However, corrected values only were used for the present paper. More significant is the fact that the pH-O_2 diagram can be used as an independent control for the water mass determinations.

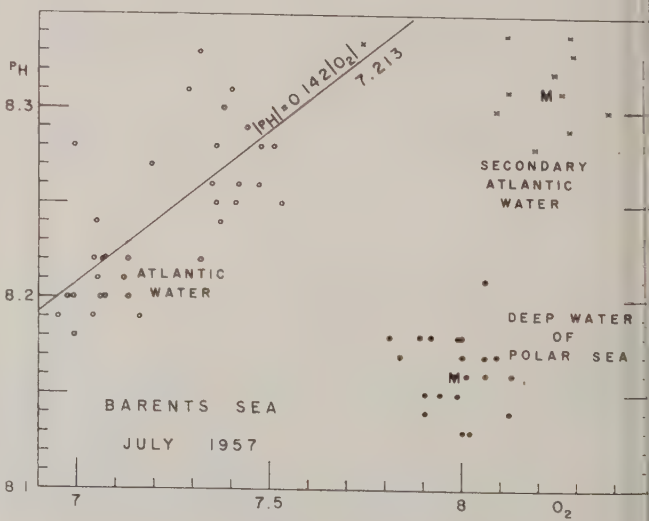

Figure 14. pH-O_2 diagram of the Barents Sea waters.

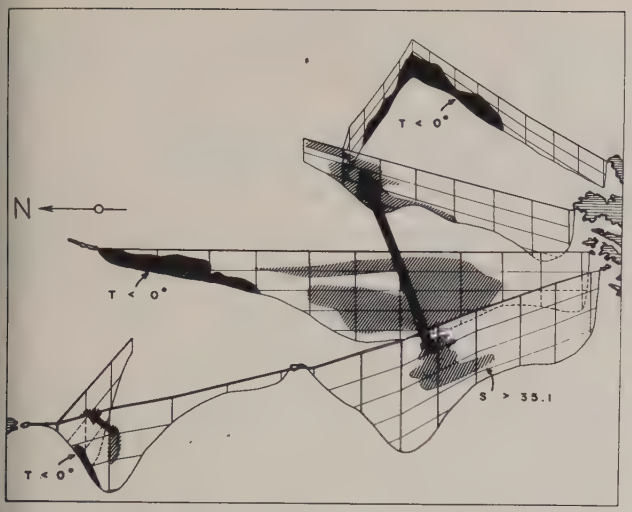

Figure 15. The "Aranda" sections in the Barents Sea in perspective drawing, with the cores of the saline Norwegian Current and the cold Deep Water indicated by hatched and black shadings, respectively.

In a perspective drawing (Fig. 15) the core of the north-easterly branch of the saline North Cape Current (hatched sections), with salinities higher than 35·1 ‰, is clearly seen. In this representation the swift coastal branch of the North Cape Current cannot be observed. The pattern is similar to the schematic model given by Schokalskij (1959) and others. The Storfjordrenna branch of the Atlantic Water between Sörkapp and Bear Island is seen as well. Finally, the penetration of the cold Deep Water (black sections), with temperatures below 0°C, into the Eastern Basin, south of Hopen and south of Sörkapp is observed.

Finally, it is interesting to compare the long-term mean temperatures and salinities with those of July 1957. The bends of the mean surface isotherms for July (Krauss, 1957) indicate the existence of the Murman Current, a southward branch of the Secondary Atlantic Water at the surface of the Eastern Basin, and the north-easterly branch of the North Cape Current along the Bear Island Channel. The Bear Island Current can be traced in the mean representation also. The surface temperatures of July 1957 (Fig. 16) partly indicate the same features. The main differences are the following: the minor branch of the Atlantic Water towards the east, north of Bear Island along the Storfjordrenna, is now much better developed. Similarly, the Bear Island Current is, on the surface, better developed and colder than the average pattern indicates. In the temperatures of the North Cape Current not much difference can be observed between the average pattern and July 1957 (cf. Lee, 1959). A comparison with the analysis of

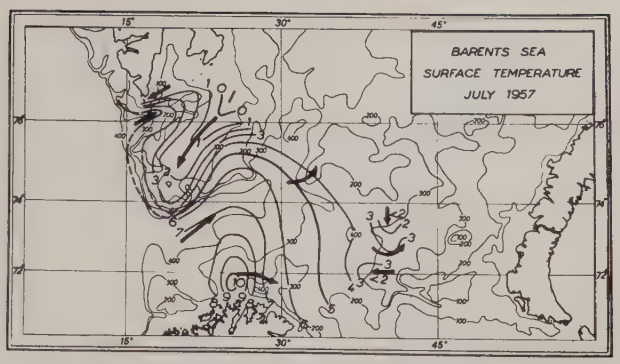

Figure 16. Surface temperatures in July 1957.

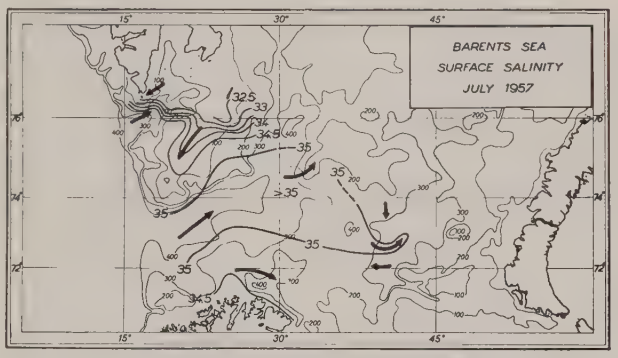

Figure 17. Surface salinities in July 1957.

Hill (1958) for 1956 shows that in July 1957 the waters of the Storfjordrenna were almost 2°C colder, those of the East Spitsbergen Current 1°—2°C colder, and those of the Bear Island Current about 1°C colder than in July/August 1956.

In the average pattern for the surface salinity (Krauss, 1957) water more saline than 35 ‰ appears only as two "islands"; one of them being in the Bear Island Channel, the other in the West Spitsbergen Current. This particular feature can be interpreted as the result of meandering or pulsation of the currents (or of upwelling as well). In 1957 surface salinities (Fig. 17) higher than 35 ‰ covered a continuous area of the two major branches of the Atlantic Current. This proves that the Atlantic influence before July 1957 had been stronger than normal (cf. Hill, 1959).

Finally, the bottom temperatures for July 1957 (Fig. 18) clearly indicate the three paths of the cold Deep Water of the Polar Sea. Compared with the "Poseidon" data of August 1927 (Schulz, 1929), the cold wedges of 1957 along the Bear Island Bank and along the Central Ridge were probably warmer than 30 years earlier. In July/August 1956 (Hill, 1958) the Bear Island Current was approximately one degree warmer than in July 1957. Further on, the analysis

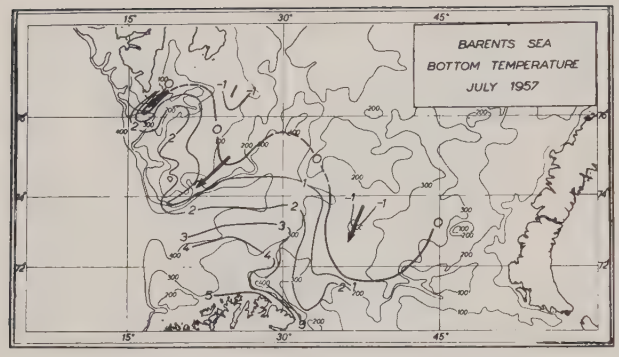

Figure 18. Bottom temperatures in July 1957.

of Midttun (1959) for October 1958 indicates that then the bottom temperatures were higher in the north-easterly branch of the North Cape Current than in July 1957. Similarly, the warm water of the Storfjordrenna was still warmer in October 1958 than in July 1957. The East Spitsbergen Current was not recognized in October 1958. The Bear Island Current temperatures were roughly the same as in 1957.

In general, in July 1957 the waters of the Barents Sea must have been warmer than the long-term July means but colder than the corresponding means based upon data from recent years (cf. Lee, 1959). During the first part of the summer of 1957 northerly winds were more frequent than normal bringing about both a strengthening of the cold currents and a retardation of the seasonal warming of the waters.

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*) Copies of these charts were kindly given us by Dr. Krauss

2.

Norwegian Hydrographical Investigations in the Barents Sea during the International Geophysical Year

By

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The Norwegian research vessel "G. O. Sars" has on two cruises in the Barents Sea (one in spring and one in autumn) worked the programme illustrated in Figure 1.

At all stations indicated temperature, salinity, oxygen, and phosphate were observed at the usual standard depths.

The material has as yet been far from fully analysed, but some main features may be seen from the series of horizontal and vertical section charts presented.

Figure 1. Network of stations.

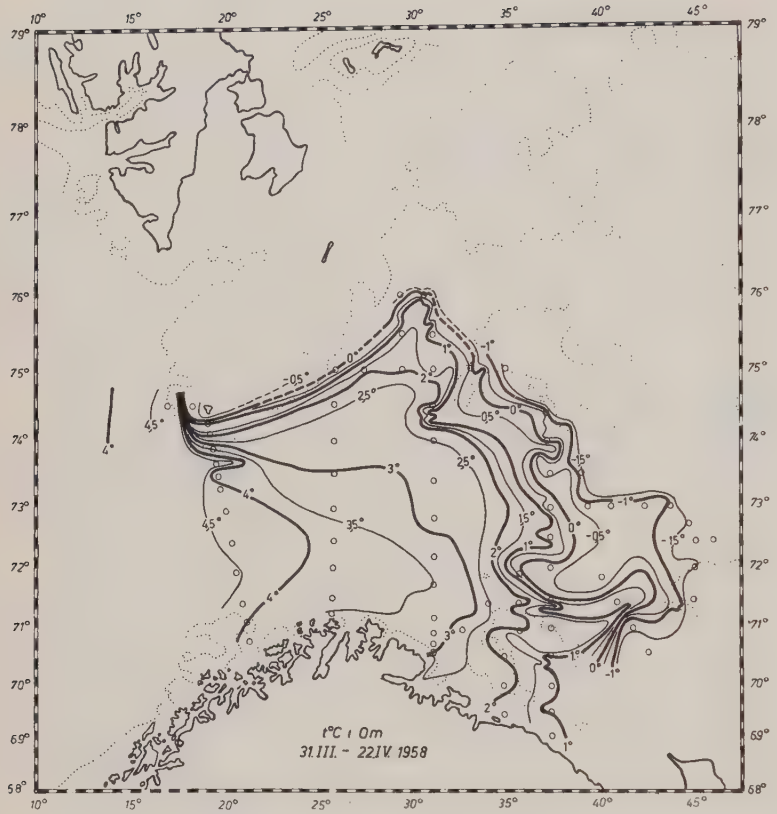

Figure 2. Surface temperature, spring.

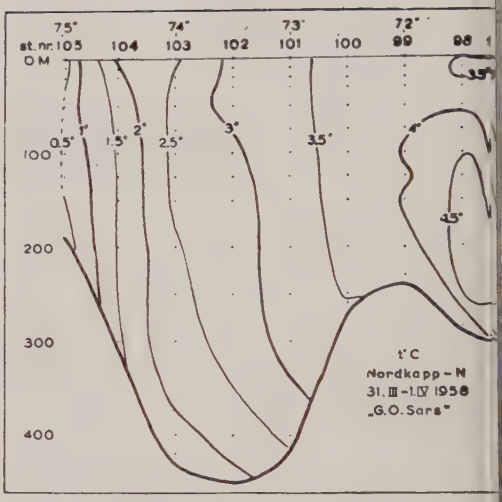

Figure 4. Temperature on the section North Cape-N, spring.

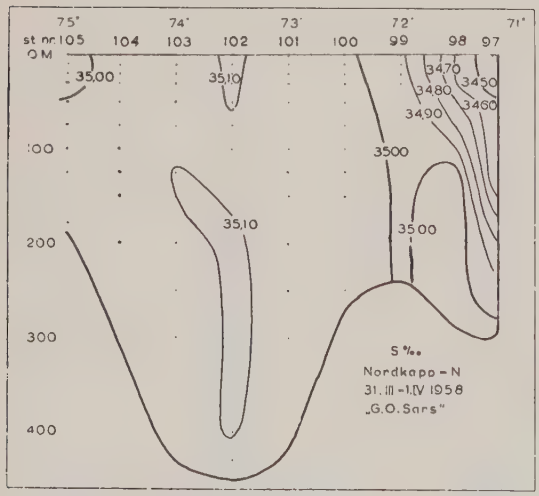

Figure 5. Salinity on the section North Cape-N, spring.

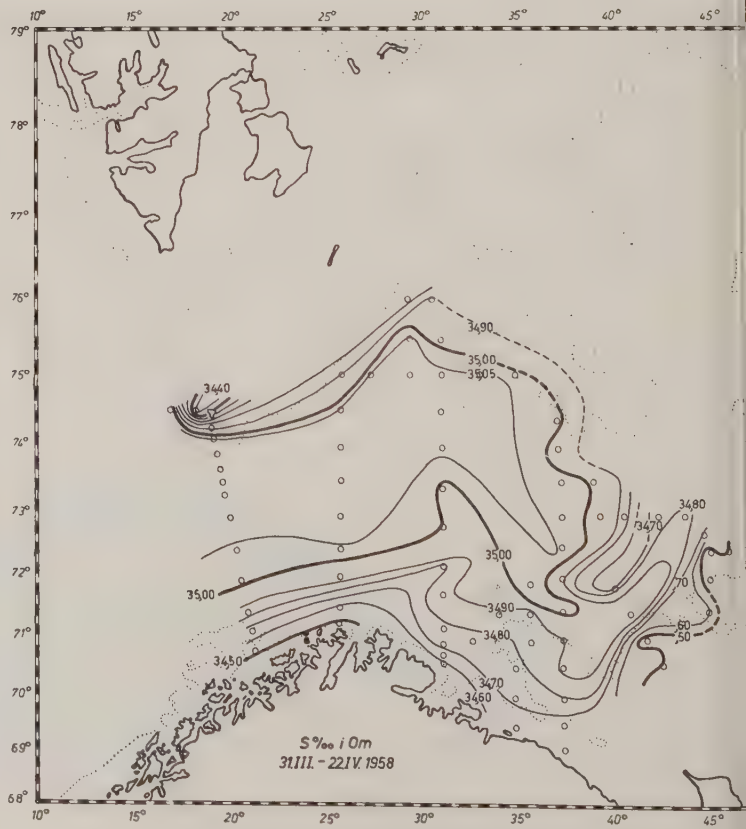

Figure 3. Surface salinity, spring.

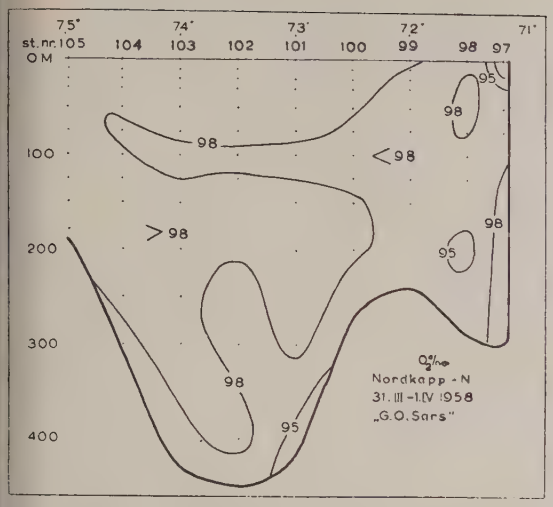

Figure 6. Oxygen content on the section North Cape-N, spring.

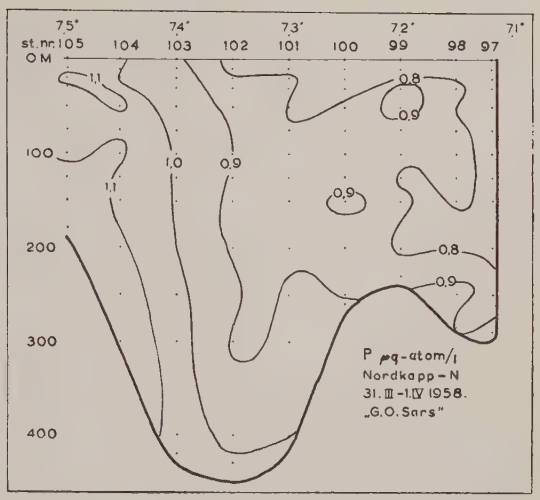

Figure 7. Phosphate content on the section North Cape-N, spring.

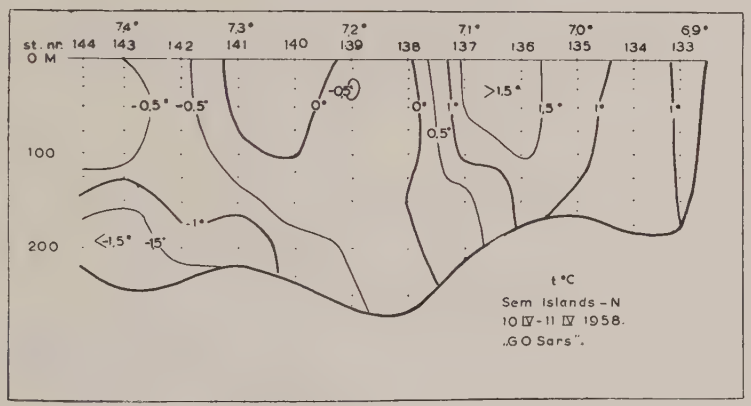

Figure 8. Temperature on the section Sem Islands-N, spring.

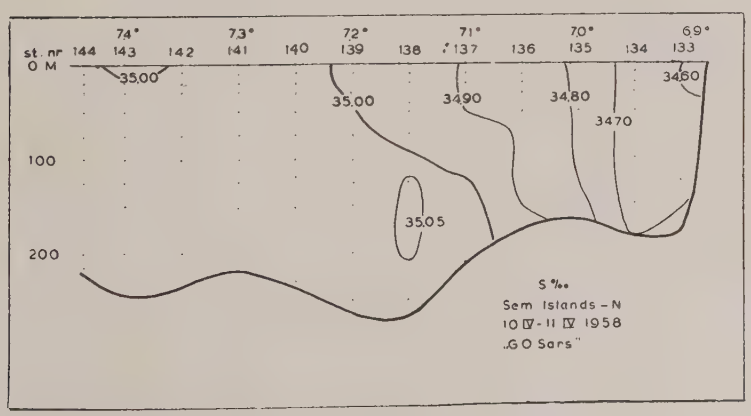

Figure 9. Salinity on the section Sem Islands-N, spring.

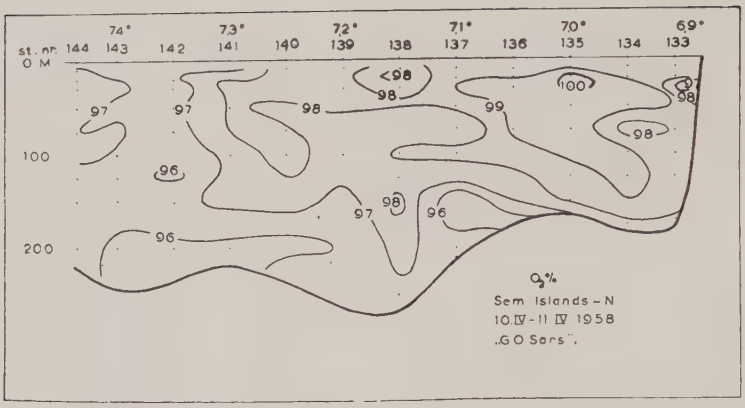

Figure 10. Oxygen content on the section Sem Islands-N, spring.

Horizontal charts

Figures 2 and 3 show the surface temperature and salinity in spring. The influence of the north-south going Central Ridge at about 35°E is clearly seen, especially from the chart in Figure 2. The temperature is changing rapidly east-west above this ridge: only in about 71°N does a tongue of warmer water penetrate eastwards across the Central Ridge, indicating inflow from the west.

Vertical sections

Conditions west and east of the Central Ridge are illustrated by means of two sections worked in spring, one from each side of the ridge.

The North Cape section (along the 25°42′ meridian) is taken to show the vertical distribution of temperature, salinity, oxygen, and phosphate in the western basin (Figs. 4—7). The southern part of the section is generally warmer, less saline, and has a slightly lower percentage of oxygen and content of phosphate, compared with the northern part.

Conditions east of the Central Ridge are repr sented by the section running north from the Se Islands (37°20′E). The above-mentioned inflow warmer water across the ridge in about 71°N visible from the temperature section chart (Fig. 8 The northern part of this section is mostly occupie by water with temperature below zero. Near th bottom north of 73°N the temperature is even belo —1·50°C with —1·90°C as the observed minimum The salinity of the cold water (Fig. 9) is abou 35·03 ‰. This water is probably formed on th Central Bank, where water of nearly the same ten perature and salinity (—1·77°C and 35·01 ‰) wa found at the surface (St. 114 in position 75°N 35°E).

The oxygen percentage of the water in the sec tion is always above 95 % (Fig. 10) and high value of phosphate were found, especially in the norther part (Fig. 11).

The vertical distributions of temperature, salinity

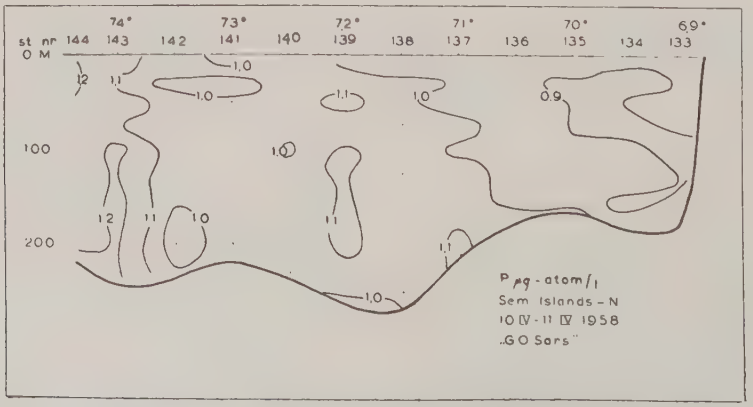

Figure 11. Phosphate content on the section Sem Islands-N, spring.

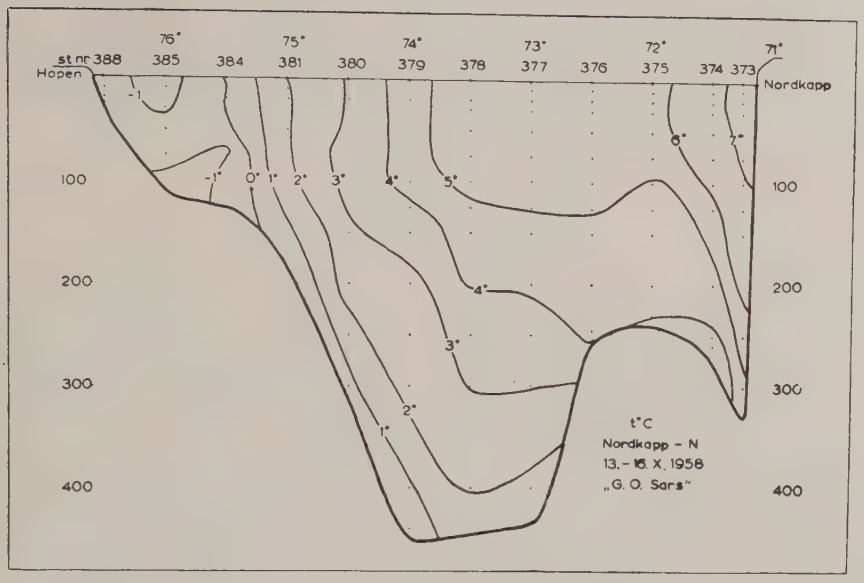

Figure 12. Temperature on the section North Cape-N, autumn.

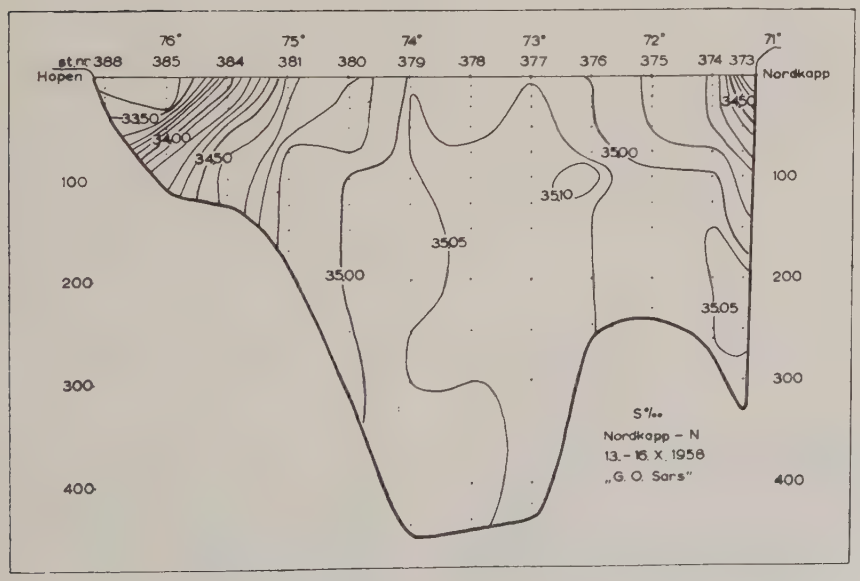

Figure 13. Salinity on the section North Cape-N, autumn.

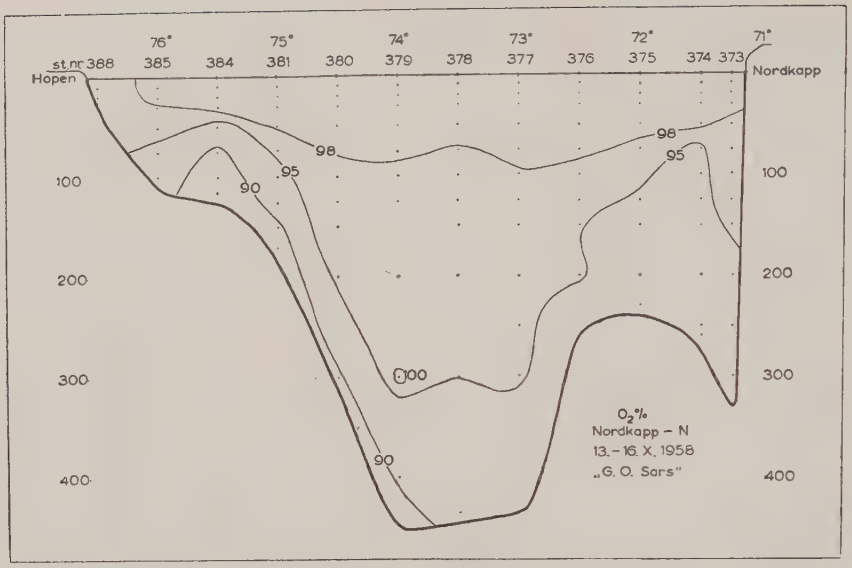

Figure 14. Oxygen content on the section North Cape-N, autumn.

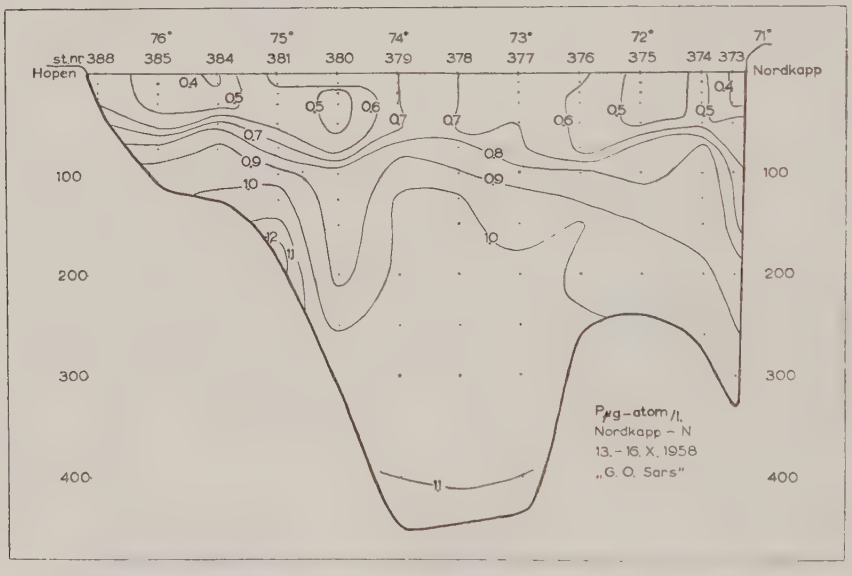

Figure 15. Phosphate content on the section North Cape-N, autumn.

oxygen, and phosphate on the North Cape section based on observations made in the autumn are shown in Figures 12–15. Generally the temperature on the section has increased since spring. Only close to the bottom north of 73°N has a temperature decrease taken place, indicating an outflow of the bottom water in this region.

The influence of ice melting in the northern pa of the section is demonstrated in the salinity section.

The oxygen observations indicate a slight decrea of oxygen in the deep water since spring. In th surface layer there is a marked decrease in the conte of phosphate, a consequence of plankton productio during the summer season.

3.

Alkalinity and Boric Acid Content of Barents Sea Water

By

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Samples and Analyses

During the cruise organized by the Institute of Marine Research, Helsinki, to the Barents Sea in July 1957 on board the R/V "Aranda", 75 alkalinity samples were collected from 45 stations. Of the latter 29 were situated in the Barents Sea proper and 16 along the west coast and north of Spitsbergen. As seen from Figure 1 the stations formed four sections across the Barents Sea: 1a, 1—9; 1b, 9—14; 2, 21—14; 3, 55—45; 4, 22—34. Section 4 was continued by the so-called "carbonic acid stations", XI—XII, from which only surface samples were collected. At the northern end of Spitsbergen lay the regular stations 39, 37, and 38, the last one situated at the northernmost point reached by the expedition, an ice-field preventing further advance. At all regular stations alkalinity samples of both surface and bottom water were collected, except at stations 1, 3, and 5 from which only surface samples were available. These bottom water samples were taken up to 50 m above the bottom, in two cases over 100 m. Details are given in Table 1; the hydrographical data quoted are taken from the work published by Hela and Koroleff (1958).

The samples were stored in Jena glass bottles and analysed six months later simultaneously for alkalinity and boric acid. To 100 ml of water 25 ml of 0·012-n hydrochloric acid were added. The carbon dioxide liberated was expelled with a current of CO_2 free air, which was passed through for at least half an hour. In the back titration 0·02-n calcium hydroxide solution was used with bromothymolblue (10 drops of a 0·01-n solution of the sodium salt) as indicator. The samples from the carbonic acid stations were titrated electrometrically with the Beckman pH-meter, model GS, using the lower sensitivity of ± 0·01 pH units. The equivalence points in 11 titrations corresponding to chlorinities from 18·61 to 19·38 showed random variations from pH 5·68 to 6·21, the mean being pH 6·0. Seven of these titrations in the presence of the indicator confirmed that the equivalence point coincides with the change from yellow to a faint but distinct green, which colour tint had been taken as the endpoint in the ordinary titrations. Later electrometric back titrations of Baltic samples resulted in equivalence points between pH 6·72 and 7·03 for salinities below 4 ‰, the mean of 13 analyses being pH 6·9, while for chlorinities ~ 6 ‰ the range was pH 6·41 to 6·79 and the mean of 3 analyses pH 6·6. The higher the salinity the lower is the pH to which we should titrate in the alkalinity back titration.

After the completion of the alkalinity analysis 5 g of mannitol were added and the titration was continued until the colour, which had again changed to yellow, showed a bluish-green tint as indicated by a buffer solution of pH 7·0 corresponding to a real pH in the solution of about 6·8. The electrometric analyses having shown that the inflection point of the titration curve of the mannitol-boric acid lies at about pH 7·4, a correction of 0·0168 meq/litre was applied, corresponding to 0·087 ml of the $Ca(OH)_2$ solution used (mean of 5 analyses). The range of the equivalence points in 13 electrometric titrations was pH 7·21 to 7·51 and the exact mean 7·42. The range of the corrections was 0·075 to 0·097 ml; the extreme values thus differed by less than a drop of the $Ca(OH)_2$ solution used. This shows that though the samples were not titrated to pH 7·4 from the beginning, a pH value which is too high to be determined conveniently with bromothymolblue, the systematical error of the analyses cannot be great. The titration error may be evaluated at ± 0·004 meq/litre.

The results of the analyses are presented in Table 1 and Figure 2. In the latter the stations are arranged in their order along the sections starting from the Norwegian coast. This brings out the differences between the sections and between the surface and bottom water. In Table 1, on the other hand, the stations are grouped according to water masses. In Table 1 and Figure 2 the alkalinities and boric acid concentrations are given in milli equivalents per litre at room temperature (about 20°C) and in the

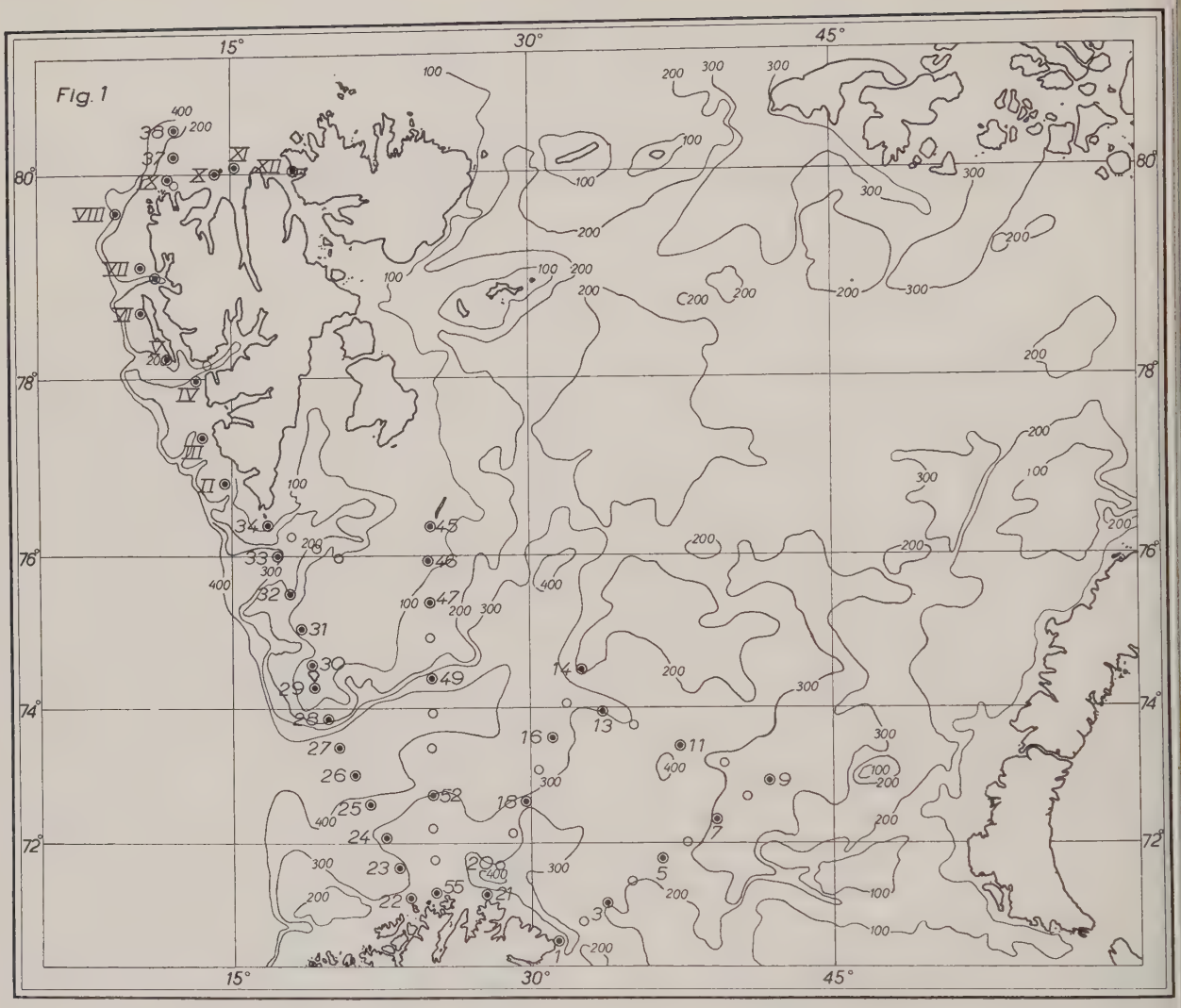

figure likewise the ratios Alk meq/litre: Cl ‰ and B mg-at./litre: Cl ‰. In Table 1, however, the latter quantities have been recalculated on a kilogramme basis.

In Figure 2 are found firstly the temperature and chlorinities at the surface and in the bottom water along each complete section, thus including the stations where no alkalinity samples were taken. Then follow the alkalinities and the boron concentrations and at the top of the figure the chlorinity ratios. A few of the alkalinity and boron analyses seem suspect when compared to other values in the same sections, as is seen from Figure 2. Since the alkalinity and boron analyses are not independent, an error in the alkalinity titration will cause an identical error in the boron value, but not vice versa. At station 5 we have a case where both values are very low and no apparent reason exists why they should be so. A station 16 the alkalinity of the bottom water is likewise very low, while in the bottom water at statio 7 and in the surface at station 28 it is, on the contrary too high. In these three cases, however, the boro values are not affected which circumstance speak for the correctness of the alkalinity analyses. In th bottom water at station 28 it is the boron conten which is much too high while the alkalinity valu is normal and this quite exceptional boron value i probably not correct. The various mean values ar presented in Table 2.

For comparison it may be mentioned that Schul (quoted by Wattenberg, 1933) found a specific alka linity (Alk meq/1: Cl ‰) of 0·1196 in the Nort Atlantic and the Barents Sea. Schulz, however, use iodometric back titration which is said to give to

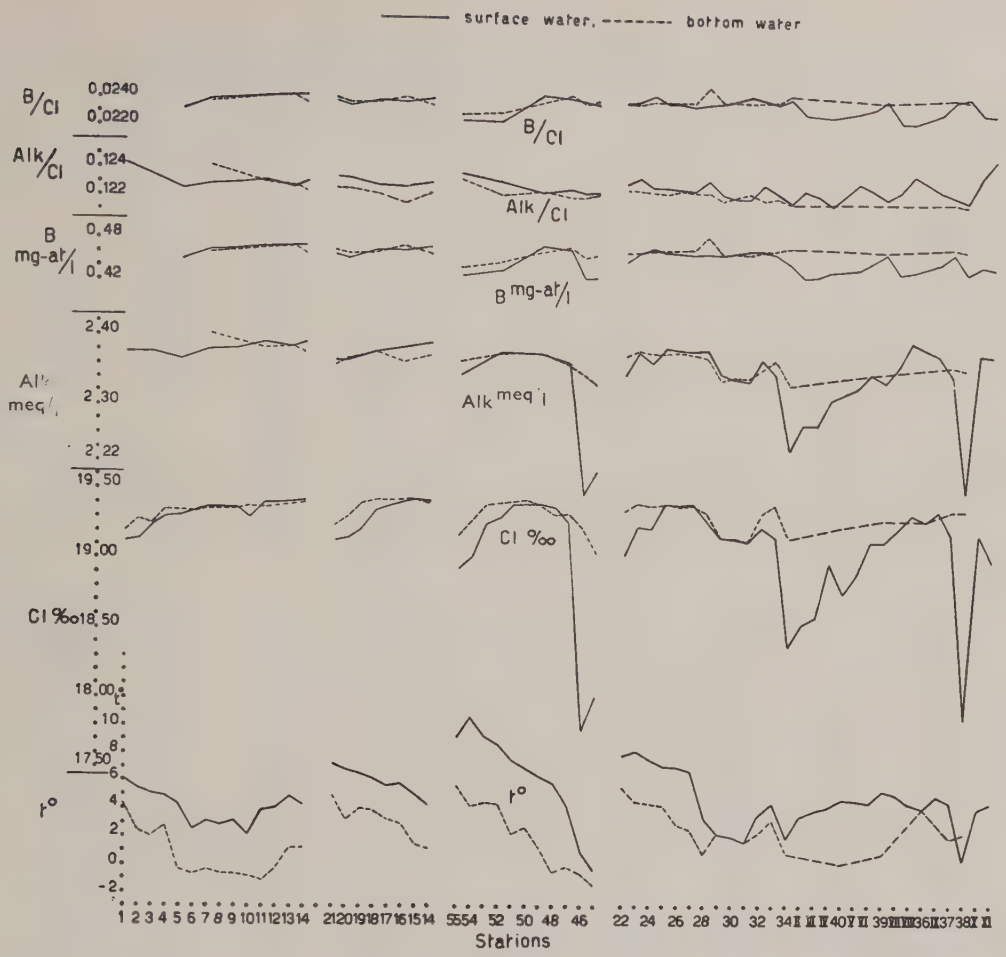

Figure 2.

low values. For the Labrador Current and the waters between Greenland and Iceland he later found exactly the same value as now obtained for all stations, or 0·1229. As for the boron ratio, Rakestraw and Mahncke (1935) reported a B g/kg: Cl ‰ ratio of 0·000255 for "water of northern origin" in the Gulf of Maine. The ratios found in the present investigation thus seem to compare well with those determined by earlier investigators on comparable material.

Discussion

Gast and Thompson (1958) as well as Noakes and Hood (1959) have recently shown that part of the boric acid in sea water may form complex anions with organic decomposition products having the character of polyhydroxy compounds. They treated sea water with oxidizing agents and found higher boron concentrations after the treatment. The differences were of the order of 0 to 0·36 mg B/1. These complex anions, formed as a result of the metabolism within the sea, may influence the alkalinity value. If the corresponding acids are as strong as the mannitolboric acid, the alkalinity will decrease, if, on the contrary, they are not much stronger than the boric acid itself the alkalinity may increase. The Baltic material, which I have presented in another paper[1]) seems to speak for the latter possibility. However, decomposing organic matter being present, the reactions involved may be more complicated than simple dissociation of hydrogen ions from the polyhydroxy boric acids formed. The important point is that variations in the alkalinity value may be brought about by other causes than precipitation or solution of calcium carbonate, hitherto considered to be the only reason for the variations observed. In future there will probably be a new interest in the alkalinity; firstly, in the alkalinity as such and in the signifi-

[1] J. Cons. int. Explor. Mer, *26* (1). 1960.

Table 1

Alkalinities and boric acid concentrations in the Barents Sea

Alk/Cl = Alk meq/kg : Cl‰, B/Cl = H_3BO_3 meq/kg : Cl‰ = B mg-at./kg : Cl‰

Depth of station m	Depth of sample m	Station	t°C	Cl‰	Alk meq/l	Alk/Cl	Mean	H_3BO_3 meq/l	B/Cl	Mean
1	2	3	4	5	6	7	8	9	10	11
Norwegian Coastal Water										
	Surface	1	6·15	19·12	2·376	0·1213		–	–	
	–	3	5·11	19·24	·377	·1205		–	–	
	–	21	7·30	19·14	·366	·1206		0·460	0·0234	
	–	20	6·91	19·16	·367	·1205	0·1207	·454	·0231	0·0231
	–	55	9·17	18·94	·346	·1210		·430	·0222	
	–	22	7·89	19·04	·346	·1203		·457	·0234	
	–	23	8·27	19·25	·382	·1207		·466	·0236	
230	181	1	4·40	19·19	–	–		–	–	
225	181	3	2·03	19·25	–	–		–	–	
229	200	21	5·08	19·24	2·360	0·1198	0·1199	0·466	0·0236	0·0232
350	300	20	3·24	19·31	·370	·1197		·462	·0232	
280	173	55	5·74	19·18	·367	·1205		·443	·0225	
320	193	22	5·71	19·36	·377	·1198		·466	·0235	
Warm High Salinity Atlantic Water										
	Surface	5	4·30	19·31	2·366	0·1195		0·449	0·0226	
	–	7	3·08	19·37	·380	·1199		·463	·0233	
	–	9	3·16	19·37	·382	·1200		·466	·0235	
	–	11	3·90	19·41	·391	·1202		·469	·0236	
	–	13	4·91	19·42	·385	·1198		·471	·0237	
	–	18	6·21	19·35	·380	·1200		·466	·0235	
	–	16	5·81	19·42	·386	·1199		·466	·0234	
	–	14	4·27	19·43	·393	·1202		·472	·0237	
	–	52	8·68	19·31	·380	·1203	0·1199	·439	·0222	0·0235
	–	49	6·37	19·41	·378	·1195		·475	·0239	
	–	47	4·28	19·28	·367	·1198		·469	·0237	
	–	24	7·67	19·24	·367	·1200		·473	·0240	
	–	25	7·19	19·42	·388	·1200		·468	·0235	
	–	26	7·13	19·41	·385	·1199		·467	·0235	
	–	27	6·84	19·42	·384	·1198		·464	·0233	
	–	32	3·69	19·24	·373	·1203		·470	·0238	
	–	33	4·57	19·18	·351	·1197		·464	·0236	
296	276	18	3·87	19·43	2·379	0·1194		0·464	0·0233	
367	319	16	2·98	19·44	·365	·1187		·473	·0237	
176	154	14	1·22	19·41	·377	·1195		·462	·0232	
308	290	13	1·19	19·40	·385	·1199		·471	·0237	
356	321	52	4·43	19·44	·378	·1193		·451	·0226	
316	299	49	1·23	19·40	·379	·1196		·466	·0234	
395	363	23	4·60	19·42	·384	·1198	0·1195	·466	·0234	0·0235
350	322	24	4·45	19·40	·381	·1197		·469	·0236	
355	323	25	4·34	19·42	·380	·1196		·469	·0236	
440	389	26	3·00	19·40	·382	·1198		·471	·0236	
466	436	27	2·62	19·40	·380	·1197		·470	·0236	
310	272	33	3·27	19·41	·373	·1193		·471	·0237	
Cold Eastern Bottom Water										
260	241	5	–0·42	19·35	–	–	–	–	–	–
269	241	7	–0·38	19·36	2·404	0·1212	–	0·460	0·0232	–
350	337	9	–0·72	19·36	–	–	–	–	–	–
268	249	11	–1·14	19·37	·384	·1201	–	·468	0·0236	–

cance of the equivalence point in the alkalinity back titration, secondly in the connexion between the alkalinity, the boric acid, and the organic matter cycle in the sea.

The variations of the chlorinity ratios in Figure 2 are not so pronounced that with their help different water masses might be distinguished. The most conspicuous feature is the high Alk/Cl ratio at the beginning of each section, that is, nearest to the Norwegian coast. The boron ratios are more uni-

Table 1 (continued)

Depth of station m	Depth of sample m	Station	t°C	Cl‰	Alk meq/l	Alk/Cl	Mean	H_3BO_3 meq/l	B/Cl	Mean
1	2	3	4	5	6	7	8	9	10	11
Cold East Spitsbergen Water										
	Surface	46	0·99	17·77	2·176	0·1198		0·429	0·0236	
	–	45	–0·39	18·02	·210	·1199		·430	·0234	
	–	28	3·38	19·30	·385	·1206		·465	·0235	
	–	29	2·29	19·18	·352	·1197	0·1197	·464	·0236	0·0237
	–	30	2·10	19·17	·344	·1194		·467	·0238	
	–	31	1·71	19·15	·342	·1194		·471	·0240	
	–	34	2·00	18·39	·243	·1192		·451	·0239	
53	147	47	–0·16	19·34	2·363	0·1193		0·473	0·0239	
08	100	46	–0·57	19·23	·349	·1193		·459	·0233	
67	50	45	–1·50	19·06	·333	·1195		·462	·0236	
65	244	28	0·86	19·36	·375	·1197		·490	·0247	
50	45	29	2·24	19·18	·342	·1192	0·1194	·465	·0236	0·0238
60	50	30	1·99	19·18	·347	·1195		·467	·0238	
55	50	31	1·73	19·15	·347	·1197		·464	·0236	
20	100	32	2·39	19·34	·361	·1192		·469	·0237	
45	38	34	0·90	19·18	·338	·1190		·475	·0242	
Warm West Spitsbergen Current										
West	Surface ...	II	3·60	18·55	2·280	0·1200		0·432	0·0229	
Coast	– ...	III	4·00	18·61	·279	·1197		·433	·0228	
	– ...	IV	4·25	19·00	·315	·1189		·441	·0226	
	– ...	V	4·70	18·92	·334	·1205	0·1198	·444	·0229	0·0229
	– ...	VI	4·60	19·15	·353	·1200		·456	·0232	
	– ...	39	5·43	19·15	·342	·1194		·468	·0238	
	– ...	VII	5·20	19·24	·365	·1200		·439	·0223	
North	– ...	VIII	4·50	19·35	2·401	0·1211		0·442	0·0222	
Coast	– ...	IX	5·15	19·38	·382	·1199		·455	·0229	
	– ...	X	4·15	19·21	·382	·1210	0·1218	·451	·0229	0·0228
	– ...	XI	4·50	19·00	·379	·1222		·445	·0228	
	– ...	XII	3·30	16·67	·120	·1246		·398	·0234	
Arctic	– ...	37	4·60	19·20	2·352	0·1196	0·1195	0·469	0·0238	0·0240
Stations	– ...	38	0·41	17·86	·181	·1194		·440	·0241	
90	275	39	0·81	19·31	2·355	0·1191		0·469	0·0237	
02	168	37	2·01	19·38	·365	·1190	0·1190	·475	·0239	0·0238
06	400	38	2·32	19·38	·361	·1189		·473	·0238	

orm, only at stations 55 and 52 of section 3 are the atios exceptionally low both in the surface and the ottom water. The identity between the "bottom" atios, however, rather seems accidental, considering he distance between the stations and the fact that t station 55, depth 280 m, the sample was taken at 07 m and at station 52, depth 356 m, only 6 m rom the bottom. It is regrettable that there are no amples from intermediate stations.

The water masses in the Barents Sea as revealed y the chlorinities and temperatures recorded in Figure 2, are described below. In fixing the limits have let myself be guided by the factor changing nost, either the temperature, the salinity, or, in ome cases, the alkalinity. The boron concentrations vere not considered in this connexion, but fit well nto the picture. Because of the high temperatures t the surface, stations 32, 33, and 47 were referred to "warm high salinity water" in spite of the fact that the surface chlorinities at these stations were not higher than 19·18—19·28, but in the depth, only station 33 was assigned to this water mass, now because of the high salinity.

Table 2
Mean values of chlorinity ratios

	All stations	Barents Sea
Alk meq/l : Cl‰	0·1229	0·1228
Alk meq/kg : Cl‰	0·1199	0·1198(5)
B mg-at/l : Cl‰	0·0240	0·0241
H_3BO_3 meq/l : Cl‰		
B mg-at/kg : Cl‰	0·0234	0·0235
H_3BO_3 meq/kg : Cl‰		
B g/kg : Cl‰	0·000253	0·000254
H_3BO_3 g/kg : Cl‰	0·001446	0·001452

The principal water mass in the Barents Sea is *warm high salinity water of Atlantic origin,* with

surface temperatures up to 10°C and surface chlorinities in the centre of the area (stations 25—27; 51—49; 16—11) from 19·40 to 19·44 ‰. Towards the Norwegian coast temperatures remain high but salinities decline. In the *Norwegian coastal water,* comprising the two first stations of each section, the highest surface chlorinity is 19·25 ‰. The principal difference between this water and the Atlantic water north thereof is the higher Alk/Cl and the lower B/Cl ratio in the coastal water. In section I temperatures decline towards the east while chlorinities increase. At station 9 the surface temperature is 3·16°C and the chlorinity 19·37 ‰. In spite of some still lower temperatures all the surface samples were considered to be of Atlantic origin. In the depth, very low temperatures appear at stations 5 to 12 indicating a *cold eastern water mass* within which, however, chlorinities remain high, 19·34 to 19·37 ‰. North of the typical Atlantic water high temperatures still prevail at stations 48 and 47, but at station 46 the surface temperature drops to 0·99°C. We come here into another cold water mass originating east of Spitsbergen and flowing in a south-westerly direction. This *cold East Spitsbergen water,* within which chlorinities vary from 17·8 to 19·3 ‰ and temperatures from —0·39° to 3·38°C, comprises stations 46, 45, 28, 29, 30, 31, and 34. Station 28, situated on the slope going down from the Bear Island Shelf to the deep station 27 (466 m), does not fit well into either the Atlantic, or the East Spitsbergen water. It was assigned to the latter, chiefly because of the pronounced drop in the surface temperature, 3·46°, from station 27 to 28, and the lower bottom temperature in spite of the lesser depth. Stations 32 and 33 belong to a tongue of warm water also including stations 42 and 43; these four stations were attributed to the Atlantic water mass. At station 34 the cold East Spitsbergen Current meets the *warm West Spitsbergen Current* moving north. The limit between the two water masses apparently fluctuates since at station 41, which has the same coordinates as station 34 and which was occupied 11 days later than the latter station, the water was almost 2° warmer. From the *Spitsbergen coastal water* only surface samples were available, except from station 39 and the "arctic" stations 37 and 38, so called because of the further distance from land. The ratios Alk/Cl and B/Cl here permit the distinction of three different water masses:—

West Spitsbergen coastal water: stations II—VI, 39, VII,

North Spitsbergen coastal water: stations VIII—XII,

Arctic stations: 37, 38.

From the mean chlorinity ratios presented in Tab 1 the following conclusions can be drawn:—

The mean Alk/Cl ratios are highest at the surfac of the North Spitsbergen coastal water and of th Norwegian coastal water, 0·1218 and 0·1207, respec tively. The lowest surface value, 0·1195, is found a the arctic stations. In the Atlantic water and th East and West Spitsbergen waters the range small, 0·1197—0·1199.

The Alk/Cl mean surface ratios are higher tha the bottom ratios. The differences range from 0·000 to 0·0008, the latter value being valid for the Nor wegian coastal water. The bottom water ratio display the same regional distribution as the surfac waters. The highest value is found in the Norwegia coastal water, the lowest in the arctic water. I the major water masses the mean bottom ratio are almost constant, 0·1194—0·1195.

The lowest and highest mean B/Cl ratios, 0·022 and 0·0240, are found in the same water masse where the highest and lowest mean Alk/Cl ratio were observed. This strongly suggests a connexio between the alkalinity and the boric acid ratios. It i however, noteworthy that the difference between th extreme boric acid ratios is about half of that betwee the alkalinity ratios. The B/Cl bottom ratios ar either higher or lower than the surface ratios. Th differences are slight and do not exceed 0·0002 They are probably not significant.

I should like to interpret these facts in the ligh of Gast and Thompson's discovery of organic bori acid complexes in oceanic water and my own result concerning the Baltic material which led to the con clusion that such complexes though much large exist in Baltic water, where they form a part of th alkalinity.

Since living organic matter is most abundant i coastal water and therefore in decomposing give rise to a greater amount of dissolved organic matte than is formed in water further from land, it i not surprising that the organic boric acid com plexes inherent in the alkalinity give rise to th highest Alk/Cl ratios in coastal water. That at th same time the B/Cl ratios display their lowest valu implies that the greatest amount of boric acid is her bound up in the organic complexes and not avail able for analysis. The fact that the Alk/Cl ratio i lower at the bottom than at the surface in the fou water masses, from which both surface and botto water samples were available, irrespective of whethe these water masses were warm or cold and the sta tions therein situated on or outside the shelf, cannot for obvious reasons, be attributed to chemical o biological precipitation of calcium carbonate, which since Wattenberg's work on the "Meteor" sample

has been considered to be the only reaction capable of bringing about a decrease of the specific alkalinity. But if in oceanic, like in Baltic water, part of the alkalinity is organic in origin, then the oxidation of this organic matter in water rich in oxygen, as is that of the Barents Sea, offers a simple explanation for the decrease of the alkalinity ratio in the bottom waters.

The general decrease of the ratios from surface to bottom is not accompanied by a marked increase of the B/Cl ratios. A tentative explanation, which of course applies to all boric acid analyses, would be that this is due to the character of the boric acid analysis in which so much mannitol is added that existing organic complexes may be in part split up in favour of the mannitol-boric acid. The polyhydroxy-boric acid complexes are formed in the presence of an excess of boric acid and the reactions involved may not be the same as those between boric acid and a great excess of mannitol. It is also possible that the organic part of the alkalinity is to a certain extent made up of anions of weak organic acids not reacting with boric acid. Experimental work on synthetic sea water might do much towards solving these problems. Further work on water from other seas will also be necessary for judging the value of the interpretation given above.

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4.

The Iodine Content of Barents Sea Water

By

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The cycle of iodine in the hydrosphere and atmosphere forms one of the most interesting problems of geophysical chemistry. Divergent views on the form in which iodine occurs in sea water have been presented by several scientists in recent years (Shaw and Cooper, 1957 and 1958; Sugawara and Terada, 1958; Johannesson, 1958). Despite the known significance of this element relatively few data on the total iodine content of sea water have been reported. The greater part of this work has been done by Sugawara and Terada using an analytical method they have developed in which the halides are precipitated with silver nitrate, the iodide converted into iodate, cadmium iodide added to the silver iodate to yield an amount of free iodine six times greater than the amount in the original sample, and finally a spectrophotometric determination is made of the complex formed by the iodine with starch. By this method they have estimated the iodine content in sea water to be about 0·30 mg-at./m^3. The previously accepted value was about 0·40 mg-at./m^3 (Harvey, 1955). Recently a new method has been developed by Dubrowcic for the determination of iodine in natural waters (1955). This method is based on the catalytic effect of iodine on the redox reactions between cerium (IV) ion and arsenic (III) compounds. Chloride ions also catalyse the reactions but by adding a large amount of sodium chloride this effect can be kept constant. Furthermore, Dubrowcic found that in a medium of high chloride content the several forms of inorganic iodine exhibit similar catalytic activity. The catalytic method of iodine determination has also been used in clinical chemistry where it is widely applied in the determination of serum iodine; this provides a very good argument for the validity of the method. When planning the work described below the author found only one value for the iodine content of sea water as determined by this method. Dubrowcic reported that Adriatic Sea water contains 0·48 μg-at./l of iodine. Therefore, in order to obtain additional data, the catalytic method was applied to the analysis of the iodine in 30 samples of sea water taken in the Barents Sea. However, in a paper presented at the First International Oceanographic Congress in New York in September 1959, Barkley and Thompso (1959) reported some results of their analyses o iodine in sea water. For total inorganic iodine the found values varying between 0·30 and 0·60 mg at./m^3; the highest values were found for sampl from North Pacific and Arctic stations.

The general sampling technique and the hydrc graphical data have been reported by Hela and Kc roleff (1958). The approximate positions of samplin stations are shown on the chart (this volume, Fig. p. 12). The water samples were collected in Pyrex gla vials which were sealed by fusion as soon as possibl The analytical method was in principle the same a that described by Dubrowcic, but, instead of stoppin the reaction by adding ferrous sulphate, the extinc tion due to the cerium (IV) ions was measured spec trophotometrically at 4200 Å after a fixed period o time. The reaction mixtures were kept in Beckma test tubes in a thermostat for 29 minutes after th reagents had been added to the water samples an mixed: the tubes were transferred during one minut to the spectrophotometer and the extinctions rea at exactly 30 minutes from the time of mixing. Th fact that the reaction mixture was not in the the mostat during the short period required for th transfer and the measurement of the extinction coul not cause any great error because the temperatur coefficient of the reaction rate is rather low, th activation energy having the value 9·27 kcal/mol (Moran, 1952). On the basis of repeated measure ments the experimental error is believed to be les than ± 5 per cent.

The results collected in Table 1 show the tota content of inorganic iodine to be about 0·50 mg at./m^3 or more, but never much less. The mea value of all analyses is 0·56 mg-at./m^3. Surfac water contains as a rule less iodine than water fro a greater depth; the mean value of the former samp les is about 10 per cent lower than that of the latte samples. The iodine values will not be discussed i detail in this connexion as the main purpose o this paper is to draw attention to our poor know ledge of the total iodine content of sea water. Exten sive studies are needed to determine why so differ ent results are obtained when different method

Table 1

The iodine content of samples of Barents Sea water

(The columns give the number of the station and its sonic depth in brackets, the sampling depth in m, temperature, chlorinity, and the iodine content in mg-at./m³.)

Station	Depth (m)	Temperature	Chlorinity	Iodine
1 (230)	0	6·15	19·12	0·46
–	181	4·40	19·16	0·52
5 (260)	0	4·30	19·31	0·54
–	241	–0·42	19·35	0·79
9 (350)	0	3·16	19·37	0·53
–	337	–0·72	19·36	0·57
14 (176)	0	4·27	19·43	0·51
–	154	1·22	19·41	0·50
18 (296)	0	6·21	19·35	0·83
–	276	3·87	19·43	0·91
20 (350)	0	6·91	19·16	0·50
–	300	3·24	19·31	0·51
22 (330)	0	7·89	19·04	0·50
–	193	5·71	19·36	0·51
26 (440)	0	7·13	19·41	0·50
–	389	3·00	19·40	0·55
28 (265)	0	3·38	19·30	0·52
–	244	0·86	19·36	0·67
29 (50)	0	2·29	19·18	0·49
33 (310)	0	4·57	19·18	0·52
–	272	2·27	19·41	0·53
38 (406)	0	0·41	17·86	0·50
–	100	3·93	19·44	0·53
–	200	2·77	19·38	0·58
–	400	2·32	19·38	0·50
45 (67)	0	–0·35	18·02	0·46
50 (440)	0	6·97	19·40	0·53
–	381	2·68	19·44	0·60
55 (280)	0	9·17	18·94	0·49
–	173	5·74	19·18	0·56

of analysis are employed, i. e., whether the differences found are caused by analytical errors, by regional and seasonal variations of iodine content, or by all these factors.

Experimental

Arsenic (III) salt solution. 1·98 g of arsenic trioxide (or an equivalent amount of sodium arsenite) is dissolved in 200 ml of water containing 1 ml of concentrated sulphuric acid. 50 g of sodium chloride is dissolved in another 200 ml of water. The clear solutions are mixed, 40 ml of concentrated sulphuric acid added, and the mixture diluted to 500 ml.

Cerium (IV) solution. 12·652 g of cerium ammonium sulphate ($Ce(SO_4)_2 \cdot 2(NH_4)_2SO_4 \cdot 2H_2O$) is dissolved in water, 44 ml of concentrated sulphuric acid added, and the solution diluted to 1000 ml.

Water. All water used was redistilled from a solution containing about 2 g of NaOH per litre.

Procedure. 20 ml of sample (or suitable dilution) is transferred to a Beckman cell test tube (22 mm) and 2 ml of arsenic (III) salt solution is added. The tubes are then placed in a thermostat so that the surface of the reagent mixture lies below the water level of the thermostat. After 20—30 minutes 2 ml of cerium (IV) solution is added to each tube of the series at intervals of one or two minutes and mixed well. During the last minute of the reaction time the test tube is transferred to the spectrophotometer (a Beckman model B was used in this work) and the extinction due to the cerium (IV) ions at a wave length of 4200 Å is read exactly after the chosen length of reaction time (counted from the moment the cerium (IV) solution was added) and again after intervals of one or two minutes.

Different calibration curves should be made for several temperatures and reaction times and when new reagents are introduced. Ten samples are prepared for this purpose from a standard potassium iodide solution containing 0·1 micrograms of iodine per millilitre. In each series of determinations the calibration curve is checked using at least three simultaneously treated standard samples.

The volume of the sample, the temperature, and the reaction time were chosen to make the differences in extinction as great as possible. At 25°C, for instance, 0·16 micrograms per 20 ml sample was the upper limit when the reaction time was 30 minutes. When the concentration of iodine exceeds this level a greater dilution or a shorter reaction time must be chosen. As in kinetic work in general, special care should be taken to keep each procedural detail constant.

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Figure 1. The main features of the atmospheric and oceanic circulations in the region of the Barents and Greenland Seas. The positions of the standard sections are also shown.

5.

Hydrographic Conditions in the Barents Sea and Greenland Sea during the IGY Compared with those in Previous Years

By

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West Bear Island Section

The research vessel "Ernest Holt" has worked a standard section, the West Bear Island Section, running westwards from Bear Island across the West Spitsbergen Current for a distance of 90 nautical miles, on 44 occasions since March 1949. For all crossings the volume transport above 400 m depth between standard station S, which lies just off the continental shelf in a depth of 930 m, and standard station W, which lies 50 miles further west, has been calculated using the 750 db. surface as reference level. The section is shown in Figure 1 and the volume transport values obtained are shown in Figure 2.

The 40 volume transport values obtained during the period 1949–58 on the West Bear Island Section, having been calculated by the hydrodynamical method derived from Bjerknes' circulation theorem, naturally show a large scatter. The results of an experiment described by Hill and Lee (1957) in which the section was worked 4 times in 48 hours suggest that the accuracy of a particular observation is ± 2 km³/hour. If we have sufficient observations the scatter can be reduced by regrouping the observations and calculating means. In order to help smooth the data and to allow for cases where the working of the section extended from the last day of one month to the first day of the next, the values of volume transport have been meaned over 5-week periods centred on calendar months. A free-hand curve was then drawn through these means and this curve is reproduced in Figure 2. For the purposes of this paper it is regarded as the norm.

It can be seen from Figure 2 that at the end of 1956 the volume transport of the West Spitsbergen Current was abnormally high, but that by May 1957, just prior to the official opening of the IGY, it was about normal. By August 1957 it was below normal and in December 1957 it was normal again. In 1958 the volume transport was the same in May as in 1957, i. e. about normal; in July it was abnormally low; and in December it was a little above the 1957 value and just above normal. It would therefore appear, taking the IGY as a whole, that the volume transport of the West Spitsbergen Current was below the norm for the decade 1949–58.

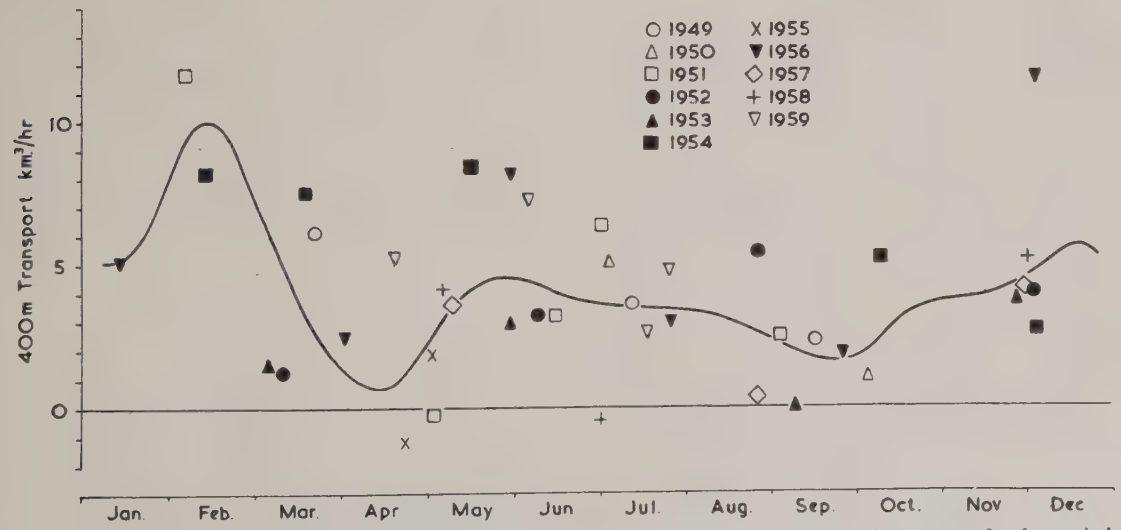

Figure 2. Volume transport across the West Bear Island Section 1949–59. The curve represents the average for the period 1949–58.

Malangen Section

During 1957—58 a section running north-westwards from Malangen for a distance of 120 nautical miles was worked on six occasions. This section is shown in Figure 1. The volume transport above 400 m between a station lying just off the continental shelf in a depth of 860 m and a second station lying 60 miles further to the north-west has been calculated using the 750 db. surface as reference level. We had not worked this section prior to 1957 and therefore have no data with which to compare those collected during the IGY. The volume transport values obtained are given in Table 1. They show the same trend as those for the West Bear Island Section. Furthermore, the values for the end of April in 1957 and 1958 respectively are nearly equal and the volume transport in June 1958 was very low; as on the West Bear Island Section. These similarities indicate that the West Bear Island Section is a reliable index of the state of the West Spitsbergen Current at the times it was worked.

Table 1
Volume transport across the Malangen Section

Date	Volume transport (km^3/hour)
1957	
20.–30. April	9·8
21.–22. August	7·2
25.–26. November	11·7
1958	
18. March	5·1
30. April–2. May	10·3
29. June	1.6

Kola Meridian

The Fisheries Laboratory, Lowestoft, has recently been supplied with the mean monthly temperatures for the 0—200 m layer along the Kola Meridian between 70°30′N and 72°30′N over the period 1900—1958. The meridian is shown in Figure 1. We are deeply grateful to the Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, for making these data available to us. In Figure 3 I have expressed the monthly means for the period of the IGY as anomalies from the 20-year grand monthly means for the period 1921—40. It can be seen that the mean temperature along the meridian was a little above normal until November 1957 when it became very much subnormal. If the anomalies from the 10-year grand monthly means for the period 1949—58 are considered the same conclusion can be drawn, but with the negative anomalies somewhat larger. Again, if the temperature anomalies for the 0—50 m layer are taken, 1958 appears to have been a cold

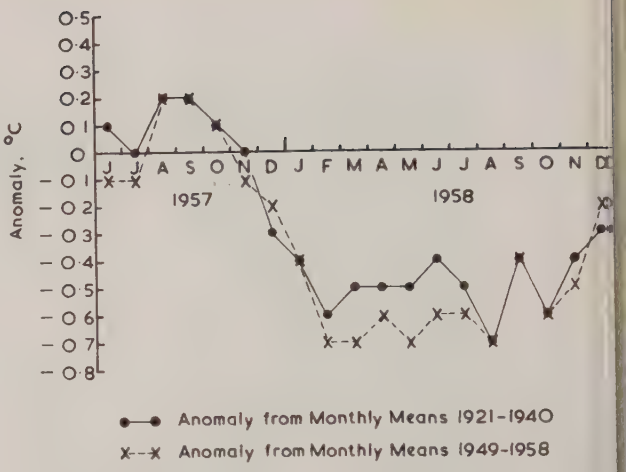

Figure 3. Monthly anomalies of temperature for the 0–200 layer along the Kola Meridian during the IGY.

year; but there is no need to show these anomali here.

The temperature along the Kola Meridian depend on the advection of warm water into the Baren Sea and on the vertical heat exchange betwee air and sea. Cooling takes place from late autum through to spring, and the intensity of the coolin during this period in a particular year still shows u in the water temperatures of the following summer.

Discussion

Figure 1 shows that the predominating feature o the mean air pressure distribution over the Norwegian Greenland, and Barents Seas is the Icelandic lo which shows a pronounced extension towards th north-east. The Arctic Front extends from Icelan to the Barents Sea. To the east and south of th front the prevailing winds are from the south-wes and are moist and warm; to the north and west o the front the winds are from the north-east and ar cold and dry. When the Siberian high is strongl developed and displaced north-westwards the Arcti Front is displaced northwards, and southerly an south-westerly winds prevail over the Barents Sea air temperatures and relative humidities increase and in those seasons when cooling of the sea normall takes place, the three processes which bring abou cooling, viz. back radiation, evaporation, and convec tion, are reduced in intensity. At the same tim winds from a southerly quarter bring about an in crease in the volume transport of the West Spitsberge Current, as shown by Hill and Lee (loc. cit.). O the other hand, when the polar high is strongly devel oped the Arctic Front is displaced southwards an north-easterly winds prevail: the cooling processe are intensified, and the advection of warm water int

the area is reduced. Thus the thermal and dynamic effects of the atmosphere upon the ocean act in the same direction and supplement one another.

Considering the average conditions over our area during the period 1949—58, the polar high is at its strongest in April, but in summer the Icelandic low moves northwards and southerly winds prevail. They decrease in September, but increase once more in October and November. In December and January the Arctic Front is situated in a more southerly position, but an increase in cyclonic activity occurs again in February, the depressions following the more northerly routes in the vicinity of Spitsbergen with the strengthening of the Siberian high.

In order to examine the atmospheric circulation during the IGY I have used the Luftdruck-Pentaden-Karten prepared by the Deutscher Wetterdienst, Hamburg. From May to July 1957 a ridge of high pressure extended from the Azores to the polar basin, the Icelandic low was displaced towards Labrador, and there was a further low pressure area over Scandinavia and the White Sea: this system gave more northerly winds over our area than is usual. In August the position was extremely variable, but in September pressure over our area was again higher than usual and the Arctic Front was displaced southwards. In October the trough of low pressure over the Norwegian, Greenland, and Barents Seas was deeper than usual and the Arctic Front was situated to the north of Bear Island: our area was covered by strong southerly winds. November and December saw the normal gradual movement southwards of the Arctic Front until a strong northerly air stream covered the whole of the Barents Sea.

In January 1958 the Arctic Front was in the mean position shown in Figure 1, but in February and March the tracks of depressions were further south over the Atlantic and a more northerly wind regime existed over the Barents Sea. In April, however, the polar high and the Icelandic low pressure systems were about normal for the month and the Siberian high pressure system was strong and extended westwards, thus establishing an unusual southerly wind regime for this month. From May to August the polar high was again more intense and extensive than usual and the tracks of depressions over the Atlantic were once more displaced well southwards, by as much as 10° of latitude, thus giving a very wet summer in Britain. The changes in the volume transport values observed on the Malangen and West Bear Island Sections during the period March-June reflected this oscillation in the atmospheric circulation, the water transport being low in mid-March, high at the end of April, and very low at the end of June. From September to November 1958 there was a negative pressure anomaly over the north-eastern Atlantic and a positive anomaly over Europe: this resulted in a south-westerly air flow from the Atlantic towards Scandinavia. In December, as is usual, pressure became high over all Arctic regions and the depressions were displaced southwards.

Thus the outstanding features of the atmospheric circulation in our area during the IGY were generally the strong development of the polar anticyclone and the consequent displacement of the depression tracks across the Atlantic. Only in October 1957, April 1958, and September-November 1958 was a southerly wind regime well established over the Barents Sea. This extreme development of the polar high was the underlying cause of the low volume transports observed in the West Spitsbergen Current and of the negative temperature anomalies observed on the Kola Meridian.

Summary

The volume transport of the West Spitsbergen Current and temperatures along the Kola Meridian are found to have been generally below normal during the IGY. This appears to have been due to the prolonged abnormal development of the polar high pressure system giving rise to a northerly wind regime over the Greenland and Barents Seas.

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6.

The Grounds, Water Masses, and Regime of the Norwegian-Greenland Basin and Adjacent Areas

By

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Summary

Deposits in the Norwegian-Greenland basin were studied by the workers of the Research Institute of Marine Fisheries and Oceanography on the basis of data collected by the Soviet expeditions in 1933/34 aboard the R/V "Persei" and in 1954/58 aboard the R/V "Professor Mesyatsev" and "Sevastopol".

The main task was to establish the relationship between the bottom relief, the distribution of water masses, and the nature of the sea-bottom deposits.

The distribution of the water masses in the Norwegian-Greenland basin adopted in this report is in accordance with the more accurate chart of the

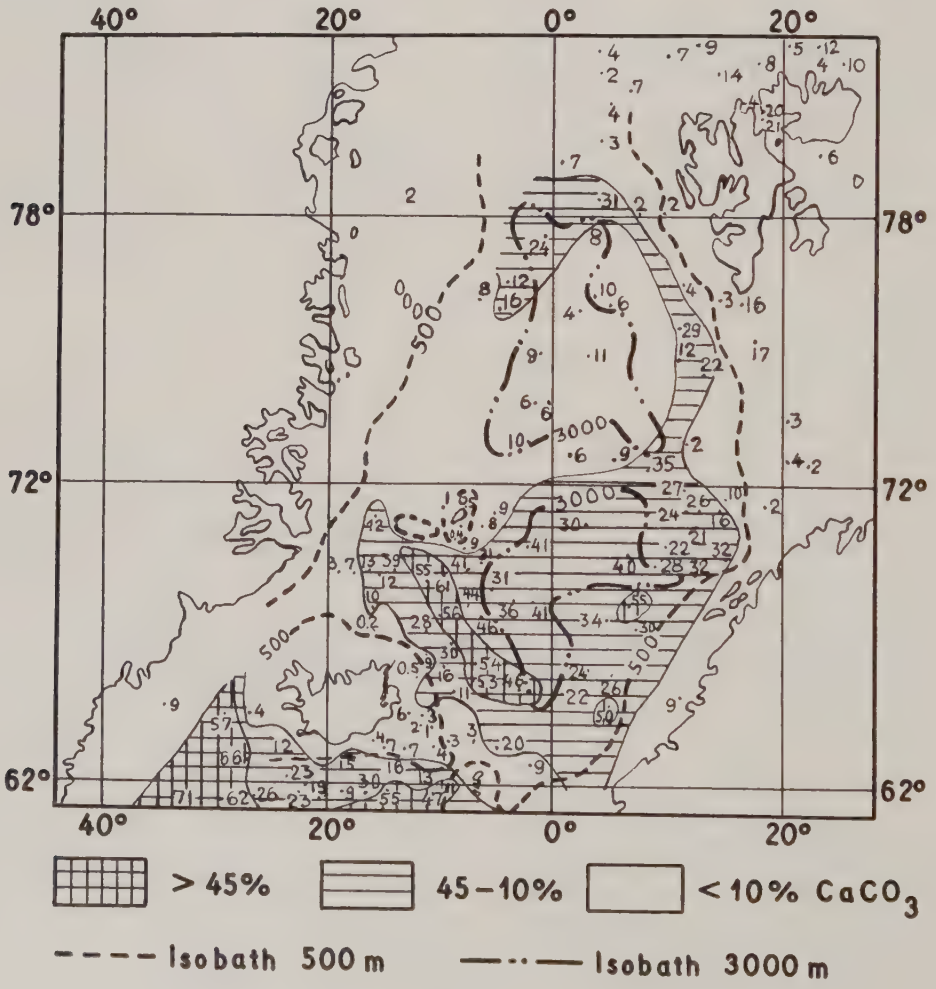

Figure 1.

currents in the Norwegian and Greenland Seas prepared by A. P. Alekseev and B. V. Istoshin. The main bulk of the water masses in the Norwegian-Greenland basin is made up of warm water coming from the Atlantic Ocean and of cold water from the Polar basin. The Atlantic water coming across elevations is deflected to the west, and the Polar water to the east. Convergence of the Atlantic and Polar waters in various areas of the Norwegian-Greenland basin is the cause of the Polar Front.

The chemical compositions of the deposits in the Norwegian-Greenland basin differ most in the content of carbonates and of manganese and iron oxides which account for the colour of the deposits.

The attached figure of carbonate distribution in the deposits of the Norwegian-Greenland basin and the Denmark Strait shows clearly that carbonate content is the highest in the deep water deposits over which flow the warm Atlantic water, and primarily in the deposits found in the zones of convergence of the Atlantic and Arctic waters.

Extensive sinking of dead rhizopods to the sea bottom with the sinking water masses can be observed in this area.

Determination of manganese in the deposits has revealed that manganese is accumulated both in the zones of convergence of the Atlantic and Arctic waters and in some of the eastern parts of the Norwegian Sea, in the zones of eddies, i. e., where the water dynamics make for the accumulation of fine-grained deposits.

It follows that the chemical composition of the sea-bottom deposits in the Norwegian-Greenland basin and in the Denmark Strait is closely related to the bottom relief and the water masses, and can therefore be used as an indicator of the distribution of the latter.

7.

Components of the Water; Thermic and Chemical Budget of the Greenland and Norwegian Seas

By

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All Union Research Institute of Marine Fisheries and Oceanography

In order to make correct forecasts of sea temperature for a given period of time it is necessary to know how and to what extent the temperature regime of the sea is influenced by various elements of the sea heat balance, whose algebraic sum in the long-term average section should equal zero.

In computing the water and heat budgets for the Norwegian and Greenland Seas we have considered these two seas as a single water basin. The values of water exchange between the Norwegian and Greenland Seas and the adjacent seas have been computed by a dynamic method. Here are the values obtained: —

	km³/hr
Via Denmark Strait	− 1·51
Iceland – Faroes	+ 1·44
Faroes–Shetland Channel	+22·99
Shetland Islands–Norway	− 0·39
North Cape–Bear Island	− 5·40
Bear Island–South Cape (Spitsbergen)	+ 0·40
Spitsbergen–Greenland	−16·25

where − = inflow into the Norwegian and Greenland Seas, and − = outflow from those seas.

The average evaporation value computed equals 610–630 mm per year (see Fig. 1).

To determine the amount of precipitation at sea we had to use observational data obtained at land and island stations. As a first approximation the total annual amount of precipitation may be considered as being equal to the annual amount of surface evaporation in the Norwegian and Greenland Seas. There remain three more elements of the water budget, namely, formation and thawing of ice and river discharge from the shores. Water loss for ice formation may be considered as being equal to the amount of water obtained from ice thawing, while the river discharge from the Norway shores is not great and amounts to about 150 km³/year.

On the basis of the water budget data obtained, the fundamentals of the heat budget were then computed. The radiation component of the latter was determined first. It was found out that the annual supply of heat through the sea surface equals $414{\cdot}12 \times 10^{15}$ kilo calories (see Fig. 2).

The annual loss of heat for evaporation was computed by the generally adopted formulae using the available data on the rate of evaporation and the average annual surface water temperatures (see Fig. 3). The value of such heat loss at the surface of the Norwegian and Greenland Seas was found to be $768{\cdot}6 \times 10^{15}$ kcal/year.

Hence, the average value of evaporation loss for the Norwegian and Greenland Seas as a whole is 29·7 kcal/cm²/year. Initial data for computing it being very few, the determination of the heat loss by turbulent exchange between the sea surface and atmosphere proved to be more complicated. We had therefore to determine the correlation between the heat losses by turbulent exchange and evaporation on the basis of the few data that do exist, and then use this correlation to compute the total value of the former value from the total value for the latter.

Based on the factor so obtained, the heat loss by the turbulent heat exchange in the Norwegian and Greenland Seas as a whole is 614×10^{15} kcal/year.

An analysis of the values obtained shows that everywhere, except in the area adjacent to the Greenland shores, the total amount of heat loss from the sea surface exceeds the total heat supply through the same surface, and advection can now be determined as the remaining member of budget equation. Since the Norwegian and Greenland Seas form a "running water" basin, its heat budget must include not only the component showing the heat supplied by currents from the outside, it must include another component showing the amount of heat carried out to the Barents Sea and the Arctic basin. Computation of those values allows us to check the correctness of the previous computations, besides providing a

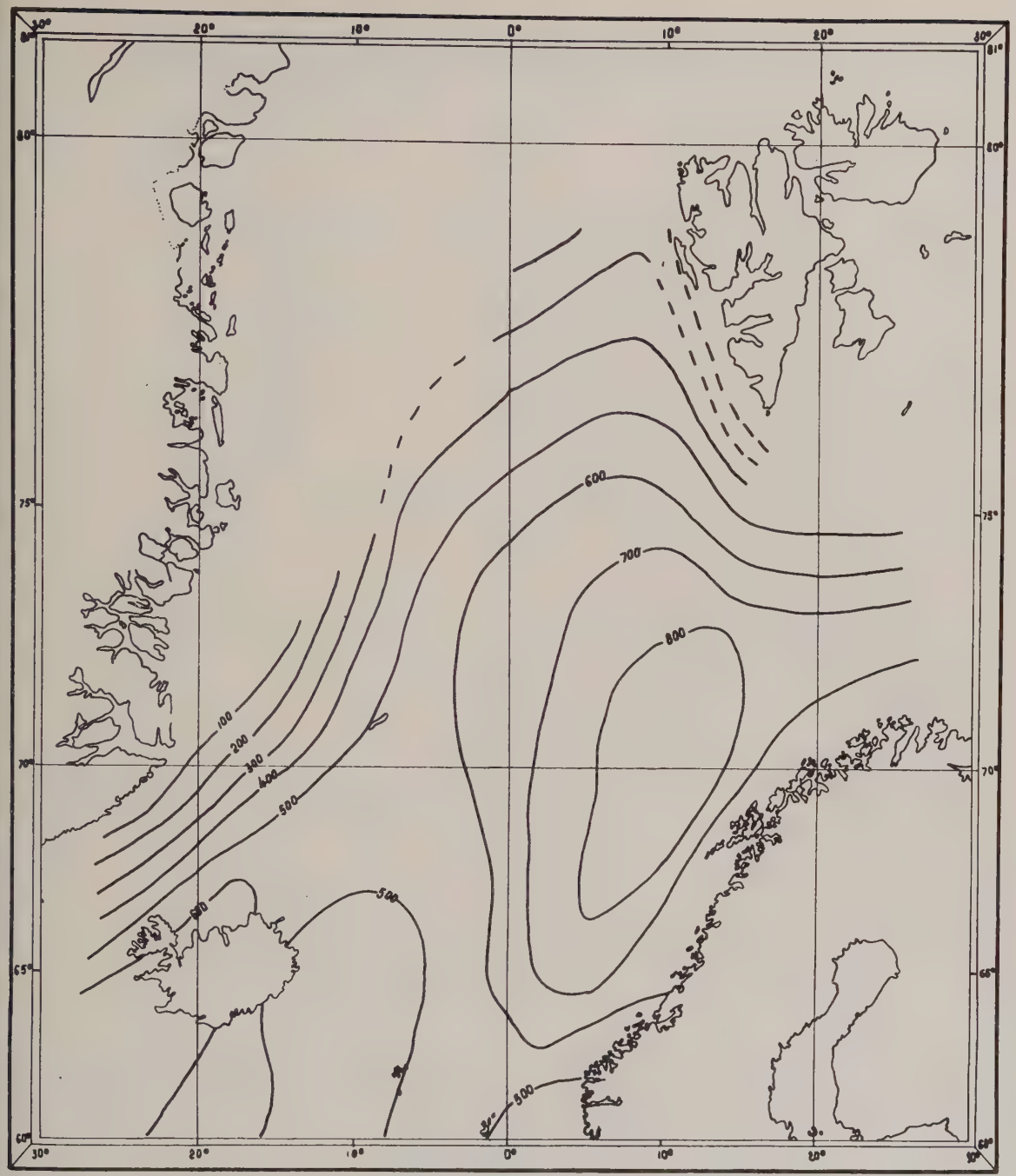

Figure 1. Evaporation from the surface of the Norwegian and Greenland Seas, in mm/year.

cture of the heat exchange between the above-entioned seas. The sum of a complete heat budget, cluding the data on heat exchange with adjacent as, must equal zero. Therefore, we have in fact calculated this heat exchange when computing the heat budget for the Norwegian and Greenland Seas. In order to determine the amount of heat brought into the Norwegian Sea through the southern straits,

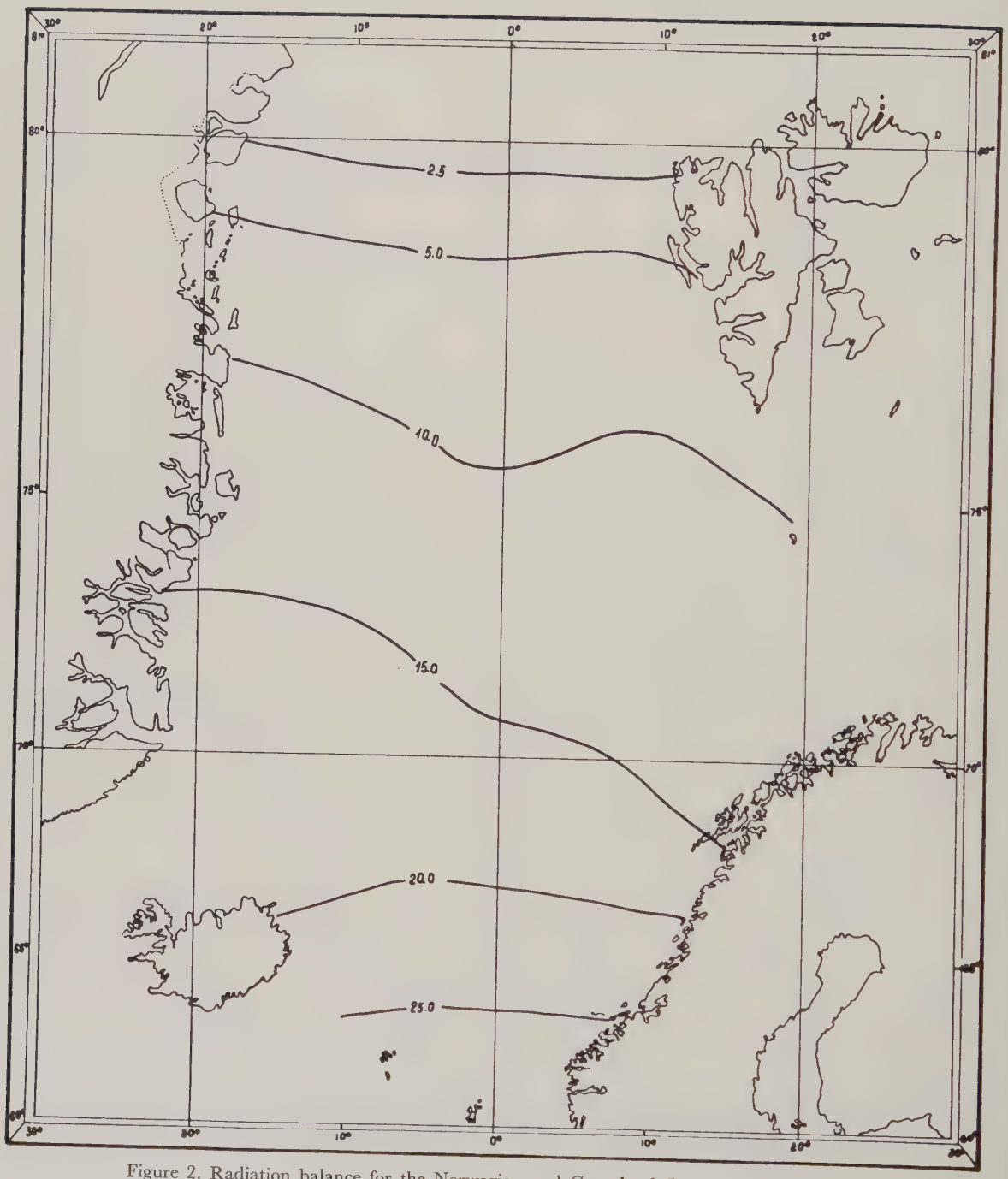

Figure 2. Radiation balance for the Norwegian and Greenland Seas, in kcal/cm²/year.

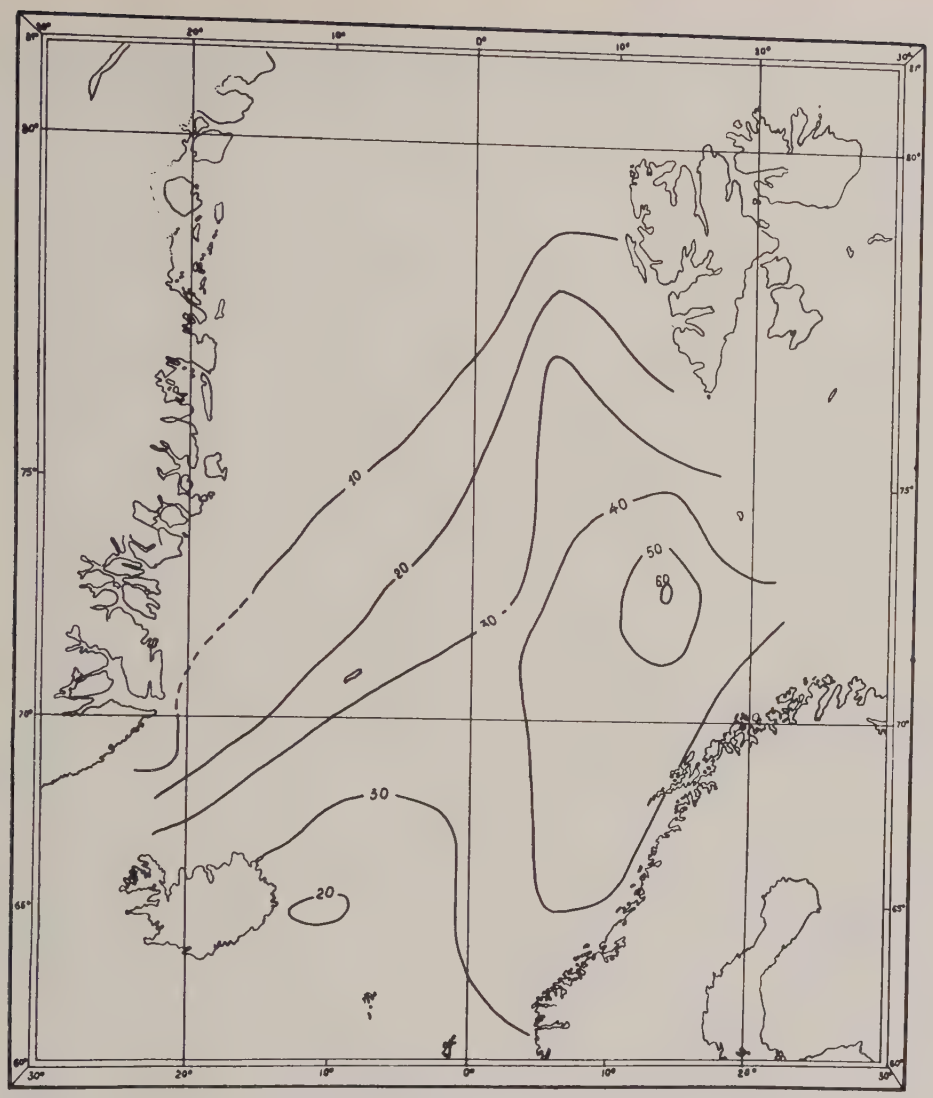

Figure 3. Evaporation losses at the surface of the Norwegian and Greenland Seas, in kcal/cm²/year.

ve have calculated the annual amount of heat supplied through each of them. The values obtained (in kcal/year) are shown below: —

ognefjord–Shetland Islands	+	$21{\cdot}3 \times 10^{15}$
aroe–Shetland Channel	+	$1854{\cdot}8 \times 10^{15}$
aroes–Iceland	+	$80{\cdot}6 \times 10^{15}$
enmark Strait	+	$72{\cdot}8 \times 10^{15}$

The total amount of heat supplied through these traits annually is $2{,}029{\cdot}5 \times 10^{15}$ kilo calories.

The amount of heat carried away annually by the North Cape Current to the Barents Sea was found o be equal to $102{\cdot}1 \times 10^{15}$ kilo calories. On the ther hand, the East Spitsbergen Current carries in $17{\cdot}7 \times 10^{15}$ kilo calories per year from the northwestern part of the Barents Sea to the Greenland Sea. As a result the total amount of heat carried away from the Norwegian Sea to the east equals $84{\cdot}4 \times 10^{15}$ kcal/year. There remains the last component of the advective heat exchange, viz. the outflow of heat from the Greenland Sea to the Arctic basin. Our computations have shown that $963{\cdot}8 \times 10^{15}$ kilo calories of heat are carried away from the Greenland Sea to the Arctic basin annually. The heat budget for the Norwegian and Greenland Seas, as we have computed it, in its final form is as follows (in kilo calories $\times 10^{15}$ per year, in round numbers): —

	In	Out
Via Denmark Strait	75	–
Faroes–Iceland	80	–
Faroe–Shetland Channel	1,855	–
Shetland Islands–Sognefjord	20	–
Solar radiation	415	–
Outflow to the Arctic basin	–	965
Outflow to the Barents Sea	–	85
Evaporation loss	–	770
Turbulent exchange loss	–	615
Total...	2,445	2,435

The difference between the supply and loss of heat so calculated amounts to only 0·4 %.

As has been said above, currents bring annually $2{,}029 \times 10^{15}$ kilo calories of heat into the Norwegian and Greenland Seas, and carry away $1{,}048{\cdot}2 \times 10^{15}$ kilo calories, the balance of heat remaining within this water basin being equal to $981{\cdot}3 \times 10^{15}$ kilo calories. Besides it receives $414{\cdot}1 \times 10^{15}$ kilo calories of heat annually by solar radiation, so the total annual supply of heat to the Norwegian and Greenland Seas amounts to $1{,}395{\cdot}4 \times 10^{15}$ kilo calories. Advection of heat by currents constitutes the lion's share of the balance, 70 %, while the local climatic factors account for only 30 % of heat lost from this basin. And if we take only the "income" part of the balance, advection accounts for 84 % and solar radiation for only 16 % of it. Figure 4 illustrates the influence of advection in various parts of the sea. The local factors predominate only in the western part of the sea, along the Greenland coast, and partly in the extreme north of it. Elsewhere advection predominates over radiation. A continuous line in Figure 4, corresponding to 50 %, represents a borderline between these two areas having different heat balances.

Because of the lack of data the processes of ice formation and ice thawing were not included into our computation. As a first approximation the effect of these two processes on a heat budget may be considered as being equivalent.

In our research work and heat budget computation we were taking into account the entire thickness of water in the Norwegian and Greenland Seas, and the correlations between radiation and advection were determined on the assumption that the entire mass of water, from surface to bottom, is involved in the heat exchange between the sea and atmosphere. Such a method of computing a heat budget was to a certain extent dictated by the already existing approach to the solution of this task. It must be admitted, that actually only a certain top "active" layer of water is involved in heat exchange with atmosphere. With this correction the results will be somewhat different. The next step in our work wi be to check the correctness of this assumption.

In conclusion the author wishes to acknowledg the contributions made by Miss L. V. Abramkina a graduate student of the Moscow State Institut who has calculated the radiation values, and t Mrs. N. V. Mertsalova who supervised the calcu lation of the evaporation value.

Exchange of water masses, naturally, makes fo exchange of biogenic elements. The final result o biogenic exchange depends upon the intensity o water flowing in both directions and upon the con tent of biogenic elements in those flows. Researc works carried out aboard the R/V "Sevastopol" an other research vessels mostly at the end of 1957, i 1958, and at the beginning of 1959, provided considerable amount of hydrochemical material whic was used as the main basis for determining the aver age constituent values of the biogenic budget, as first approximation of the Norwegian-Greenlan basin.

More primary material on biogenic elements wa collected in the southern, south-eastern, and easter areas of water exchange than in the northern areas However, some hydrochemical material was availabl for the northern areas: we obtained it during th IGY. We have also used data obtained during th cruises of the R/V "Aranda" and R/V "Anto Dohrn". As a result of some analyses and compu tations already completed we have arrived at quan titative characteristics (see Table 1) and have con cluded that the Atlantic waters flowing through th Iceland—Scandinavian straits bring into the Nor wegian—Greenland basin the main bulk of phospho rus, nitrogen, and silicon, both in mineral an organic compounds.

Most of the biogenic elements going southwar from this basin are carried through the Denmar Strait. The amount of biogenic elements in minera compounds carried that way is several times les than that brought in by the Atlantic waters. Fo mineral compounds of phosphorus and silicon i is about ten times less. Most of these are carrie away to the north, into the Arctic basin, and to th east, into the Barents Sea. The total amount o

Table 1

Values characterizing exchange of phosphates betwee the Norwegian-Greenland basin and adjacent seas, in millions of tons

	Phosphat
Via Denmark Strait	−0·3
Straits between Iceland and Scandinavia	+4·5
Between Greenland and Spitsbergen	> −2·0
Between North Cape and South Cape	−1·0

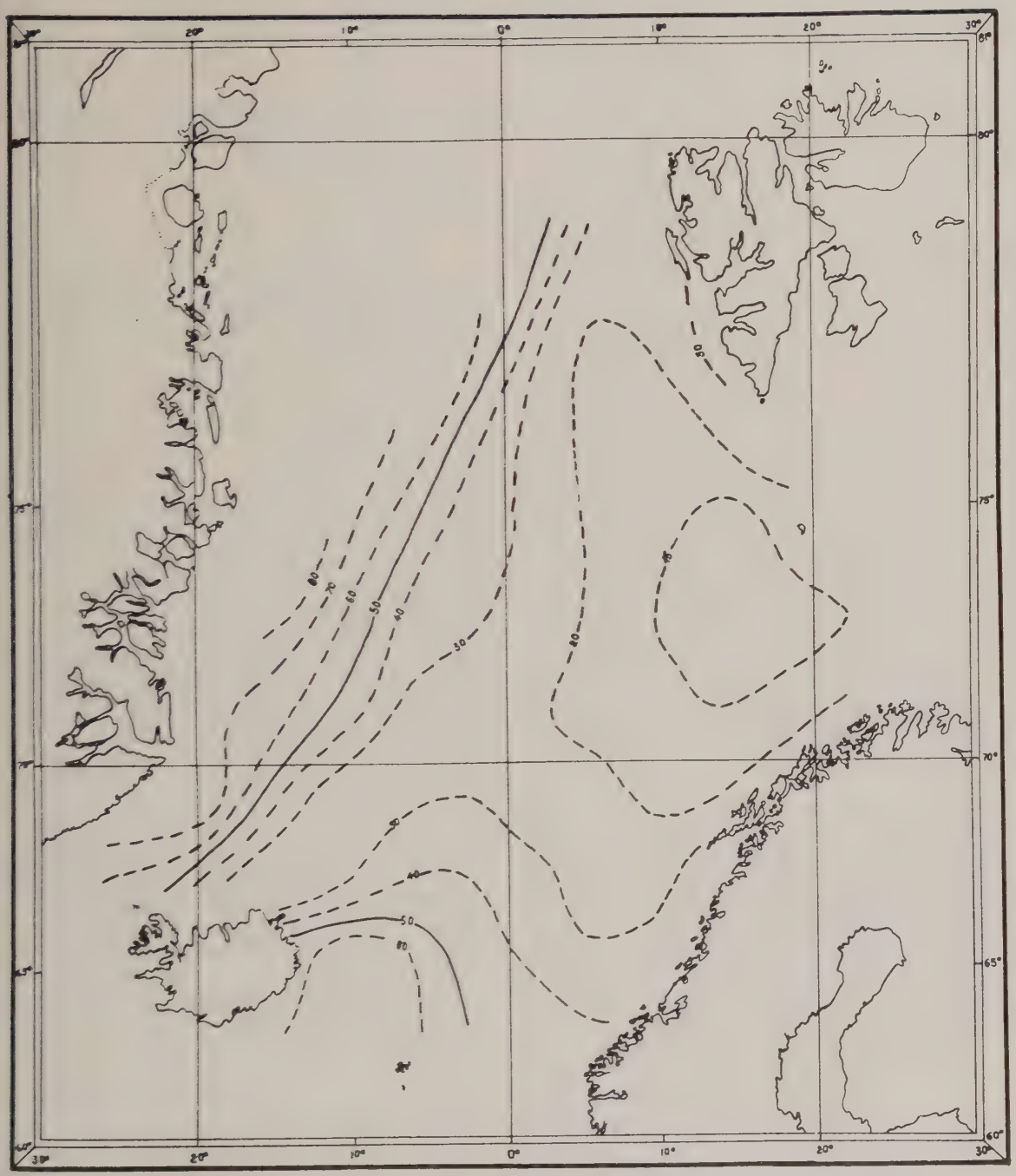

Figure 4. Effect of radiation factors on the heat balance in the Norwegian and Greenland Seas, (%).

mineral compounds of phosphorus and nitrogen carried into the Barents Sea is 3—4 times more than that carried via Denmark Strait, and the amount of mineral compounds of phosphorus carried to the north is 6—7 times more than that carried via Denmark Strait. The difference is still more striking in the case of dissolved silicon compounds.

The above data are enough to show that the Norwegian—Greenland basin is being fed with mineral salts of biogenic microelements brought in mostly by Atlantic waters, although we have determined the content of biogenic elements in these waters as being lower than that observed in the waters coming into the Norwegian—Greenland basin from the north.

Further work along this line will enable us to make a thorough evaluation of the chemical basis for primary production in the water basins under consideration.

In the process of the work one more additional question came up. Although its solution was not necessary for solving the task we had set ourselves, it was interesting in itself; it was the question of the water exchange between the Central Arctic basin and the Atlantic and Pacific Oceans.

As is known, the Atlantic Ocean plays a decisive role in this water exchange. An analysis of the data we have obtained permits us to elucidate the quantitative aspect of this question, as a first approximation. It was discovered that the main bulk of the water mass comes to the Central Arctic via the Norwegian and Greenland Seas, whereas the outflow of water from the Arctic mainly takes place through the Canadian straits, and eventually via the Davis Strait.

The following are two versions of this budget, the "southern" and the "northern" ones.

"Southern" version	km³/hr
Via Denmark Strait	— 1·51
Iceland–Faroes	+ 1·44
Faroe–Shetland Channel	+ 22·99
Shetland Islands–Norway	— 0·39
Bering Straits[1])	+ 4·50
Outflow via the Davis Strait...	— 27·03 km³/hr

"Northern" version	km³/hr
North Cape–Bear Island	+ 5·40
Bear Island–South Cape	— 0·43
Spitsbergen–Greenland	+ 16·25
Bering Straits[1])	+ 4·50
Outflow via the Davis Strait...	— 25·72 km³/hr

Where + = inflow into the Arctic Basin,
— = outflow.

[1]) According to G. Ratmanov.

It may be seen that these two versions practically coincide, the difference being only about 4 %, which is quite permissible in the given case.

Average flow velocities of 0·5—0·6 knot in the narrowest part of the Davis Strait, between Capes Dyer and Holsteinsborg are necessary to give the values of outflow obtained. Such velocities are also quite possible. However, it should be borne in mind that the figures reported represent only the first attempt to compute the above exchange.

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II. NORWEGIAN SEA

8.

Results of Hydrological and Hydrochemical Studies in the Norwegian Sea in 1958

By

A. P. Alekseev, G. N. Zaitsev, and S. I. Potaichuk

In accordance with the programme of the International Geophysical Year, the oceanographic vessel "Sevastopol" made two trips to the Norwegian Sea in 1958. Its first cruise lasted from 20. March to 3. May and was headed by Mr. A. P. Alekseev. The second one was made between 22. September and 31. October under the general leadership of Mr. G. N. Zaitsev. The hydrological work in both cases was directed by Mr. S. I. Potaichuk. Both times the "Sevastopol" followed the route approved by the 45th session of the International Council for the Exploration of the Sea in Bergen, in 1957. This route included ten sections with 110 or 112 stations. The direction of these sections was chosen so that, as far as possible, it would always be perpendicular to the direction in which the water masses flow at any given place. The programmes of both these cruises provided for the collection of the greatest possible amount of material required for the solution of the problems set by the programme of the International Geophysical Year, namely: the problem af the oceanic water structure and water masses; of the interaction between the ocean and atmosphere; the ocean heat balance; the chemistry of ocean water; bottom relief and its origin; bottom deposits and their origin; and the biology of the ocean.

In the light of these tasks members of both expeditions were selected. Besides hydrological investigations, meteorological, hydrochemical, biological (plankton and benthos), and geological observations were also made during both these cruises.

This paper gives only the preliminary results of an analysis of hydrological data collected during the two cruises. A review of all other data obtained will be given elsewhere.

During the first cruise westerly and south-westerly winds prevailed in the Norwegian Sea, their velocity ranging from 3 to 9 metres per second. Cyclonic activities were especially strong at the beginning and at the end of the cruise. Cloudiness on the average was from 6 to 8. The average daily air temperature ranged from 0.8° to 9·2°C, depending more upon the synoptic situation than upon the latitude.

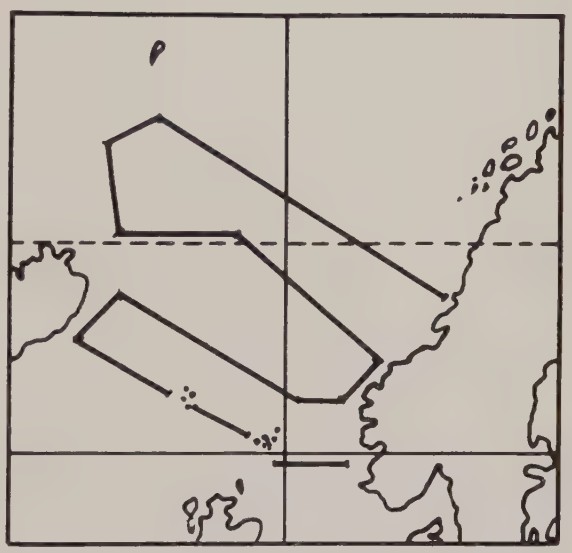


Figure 1. Cruise map of the R/V "Sevastopol".

From the hydrological point of view, the spring of 1958 was characterized by water temperatures somewhat lower than the long-term average values. The temperature regime of the active water layer determined by the intensity of inflow of the Atlantic waters, was also below the average for the ten years 1948—58. April 1958 was notable for widening of a branch of the East Icelandic Current towards the east so that the Norwegian Current had become tightly pressed to the continental slope in latitudes 64° to 65°30′N. As a result, the horizontal salinity and temperature gradients rose both at the western edge of the latter and at its junction with the coastal waters. The cold Baltic water front in April was in latitude 62°N. The intensity of inflow of the Atlantic water is determined by the water exchange via the Faroe—Shetland Channel. The section across the channel was notable for its dome of cold waters of low salinity. At the beginning of April 1958 it was pressed to the western slope of the channel, but two weeks later it shifted to the centre of the channel

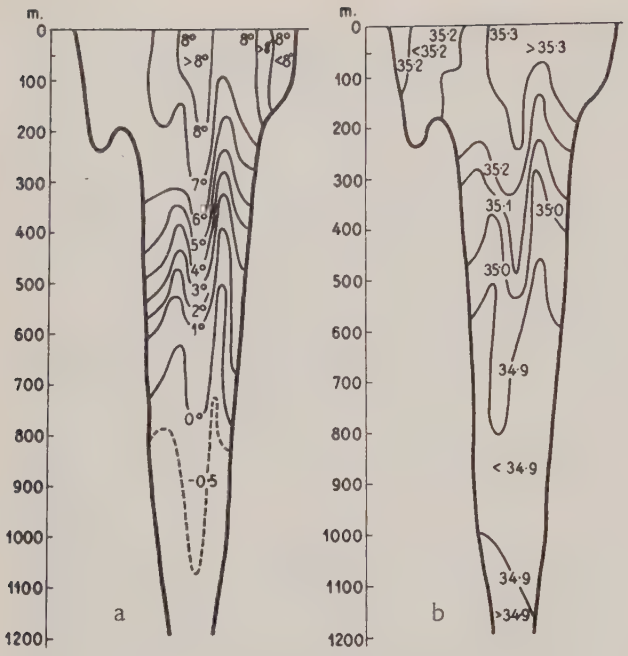


Figure 2a. Temperature on the Faroe–Shetland section 16.–17. April 1958.
Figure 2b. Salinity on the Faroe–Shetland section 16.–17. April 1958.

and was divided into two parts by a stream of Atlantic water. Such sharp changes, taking place within a short period of time, testify to the complicated nature of water dynamics in the area of this channel. Shifting of the dome, which had already been observed here before, should apparently be considered as one of the major peculiarities of the channel's hydrological regime. It might be assumed that such a shifting is caused by the fortnightly changes in tide and winds prevailing in that area.

The data on the distribution of near-bottom temperatures and salinity in the deep area of the sea proved to be the most interesting of all the data collected during the spring cruise of 1958. Analysis of these data leads to a new conception of the formation of the deep waters and of their dynamics. The fact that the salinity of the near-bottom waters in the entire central part of the Norwegian Sea is from 34·87 to 34.88 ‰ shows that these waters are related to the waters of the East Icelandic Current. As a result, it must be assumed that the bottom water of the Norwegian Sea flows in from the area of the East Icelandic Current in a counter-clockwise direction and, apparently, has little connexion with the bottom water of the Greenland Sea, the temperature of which is below —1°C and the salinity of which is above 34·0 ‰.

The maximum velocity of the current movin northward in the eastern half of the Faroe—Shetlan Channel, as computed by the dynamic metho reached 45 cm/sec. at the surface gradually decrea ing with depth.

The high percentage of oxygen saturation in th near-bottom waters, which was also observed durin the spring cruise, is worth mentioning. The obse vations were made during the period of late biolog cal winter and early spring. In the places of mas development of phytoplankton (mostly at the No wegian shores) reduced content of phosphorus an increased content of oxygen were registered. Fo instance, in the upper layers of the coastal are between latitudes 65° and 66°N, the oxygen satura tion of the water increased on the average by 5 % during April, while the phosphorus content droppe by 10 to 15 mg/m³.

At the beginning of the autumn cruise westerl and north-westerly winds were prevailing, their forc ranging from 3 to 5, but at the end of October th direction and force of winds changed sharply, an southerly winds prevailed all over the Norwegia Sea, their force being 7 to 8.

Observations made in the autumn of 1958 not onl

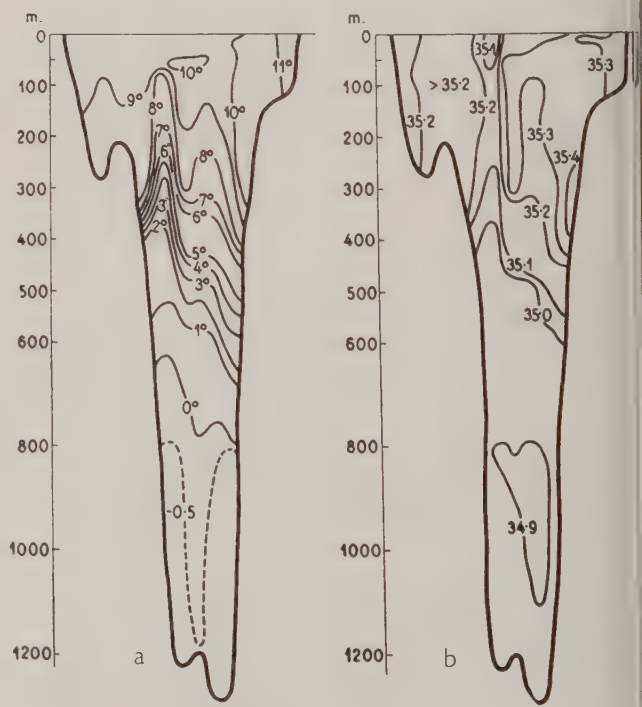


Figure 3a. Temperature on the Faroe–Shetland section 23.–25. October 1958.
Figure 3b. Salinity on the Faroe–Shetland section 23.–25. October 1958.

give an idea of the autumn regime of the sea, but also allow us to analyse the seasonal changes in that regime. One of the most important areas explored during the autumn cruise was the area of the southern straits, primarily the Faroe—Shetland Channel. The main bulk of the warm Atlantic waters comes into the Norwegian Sea via this channel. The "Sevastopol" made a section across that channel on 23. to 25. October. Data obtained aboard the "Scotia" on 28. to 30. October 1951, were available for comparison. Temperature conditions for the two years may be considered as similar. Water temperatures in the active upper layer, from the surface to the depth of 150 m, in both cases ranged from 9·4° to 9·7°C. The 9° isotherm ran at a depth of 100 to 150 m in the western part of the channel, and went down to the depth of 300 m in its eastern part. The temperature of the upper water layers in the eastern part of the channel was above 10°C. The positions of the domes of cold water also coincided. The course of isohalines coincided with that of isotherms. The salinity at the surface in 1951 was 0·1 ‰ higher than in 1958. As compared with the previous cruise of the "Sevastopol", the position of the dome of cold water had changed and the temperature of the upper water layers all along the section in October was higher than in April, by approximately 3°. The temperature of the lower layers did not change essentially. The course of the isotherms changed only slightly. The higher salinity of the upper layers observed in October leads to the conclusion that the temperature rise was caused by the intensification of the inflow of Atlantic water.

Comparison of the hydrological conditions observed in October and in April on the Faroe—Iceland section shows a general temperature rise in October by approximately 2° all over the section. Compared with the temperature of the main current in the Faroe—Shetland Channel, the temperature of the Atlantic water in this section is somewhat lower. The courses of the isotherms in April and October were the same. The lower near-bottom temperature and salinity observed in the central part of the Faroe—Shetland Channel were apparently caused by the East Icelandic Current.

On the Shetland Islands—Sognefjord section, which was run on 25.—26. October, a temperature rise of 4·5°C in the western part and of 6° to 6.5° in the eastern part, as compared with April, was observed.

Analyses of the sections located north of the straits and comparison with the ones made in the spring lead to the conclusion that in October the intensity of warm streams increased. This assumption is backed by the temperature and salinity rise in these sections. An analysis of the horizontal distribution of hydrological elements, as observed during both the spring and autumn cruises, leads to the following conclusions:

1. The general geographic distribution of the water masses remained unchanged.
2. The value of the horizontal temperature gradient in the upper layers decreased considerably.
3. No essential temperature change was observed at greater depths.
4. According to the data obtained during the autumn cruise, the area of near-bottom waters having salinity below 34·9 ‰ decreased as compared with the March—April period.

Previous investigations have shown that the bottom waters of the Norwegian Sea come from the area of the East Icelandic Current and have no close connexion with the bottom waters of the Greenland Sea. Therefore, the shrinkage of the area occupied by near-bottom waters with salinity below 34·9 ‰ observed aboard the "Sevastopol" during its autumn cruise, may be explained by the intensification of the interaction between the Atlantic water and the waters of the East Icelandic Current. G. K. Izhevski has established that the hydrological regime of the next year is shaped by the preceding winter beginning in October. Therefore, the data obtained on board the "Sevastopol" during the autumn cruise allowed us to make a forecast that the temperature regime of the Norwegian Sea in 1959 would be higher than in 1957 or 1958, which in turn were somewhat below normal. Observations made aboard the "Sevastopol" in the same areas in April and May 1959, confirmed the above assumption.

Besides the "Sevastopol", the research vessel "Polyarnik" belonging to the Murmansk section of the Hydrometeorogical Service was cruising at the same time, in both cases. The "Polyarnik" was cruising north of the area explored by the "Sevastopol" and made two sections.

Data obtained from these sections are in agreement with the above conclusions. They are being processed.

Material collected during all the cruises described above underwent primary processing and was turned over to the World Data Centre B in Moscow in due time.

9.

Preliminary Report on the Hydrographic Sections made in the Norwegian Sea 1958 by the Geophysical Institute, Bergen

By

Odd H. Sælen

Geofysisk Institutt, Bergen, Norway

In connexion with the Polar Front Survey Programme, the R/V "Helland Hansen" of the Geophysical Institute in Bergen occupied two sections in the Norwegian Sea. Hydrographic observations were made on the two sections at two different seasons: the first cruise took place in March and the second one i October. The location of the sections in March shown in Figure 1. The route followed in Octobe was almost identical with that of March. Accordin to the plans for the Polar Front survey, the sam

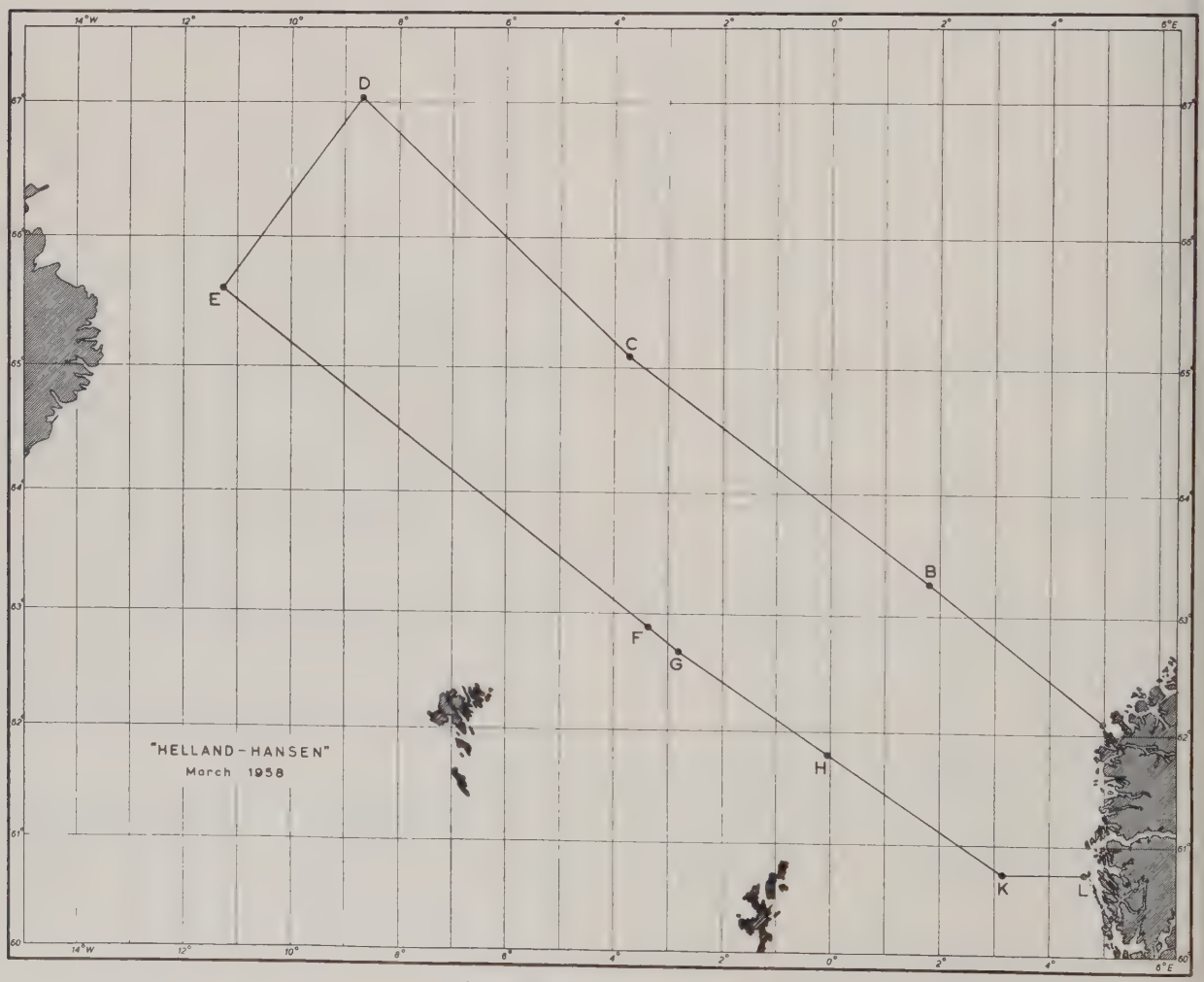


Figure 1. Location of sections.

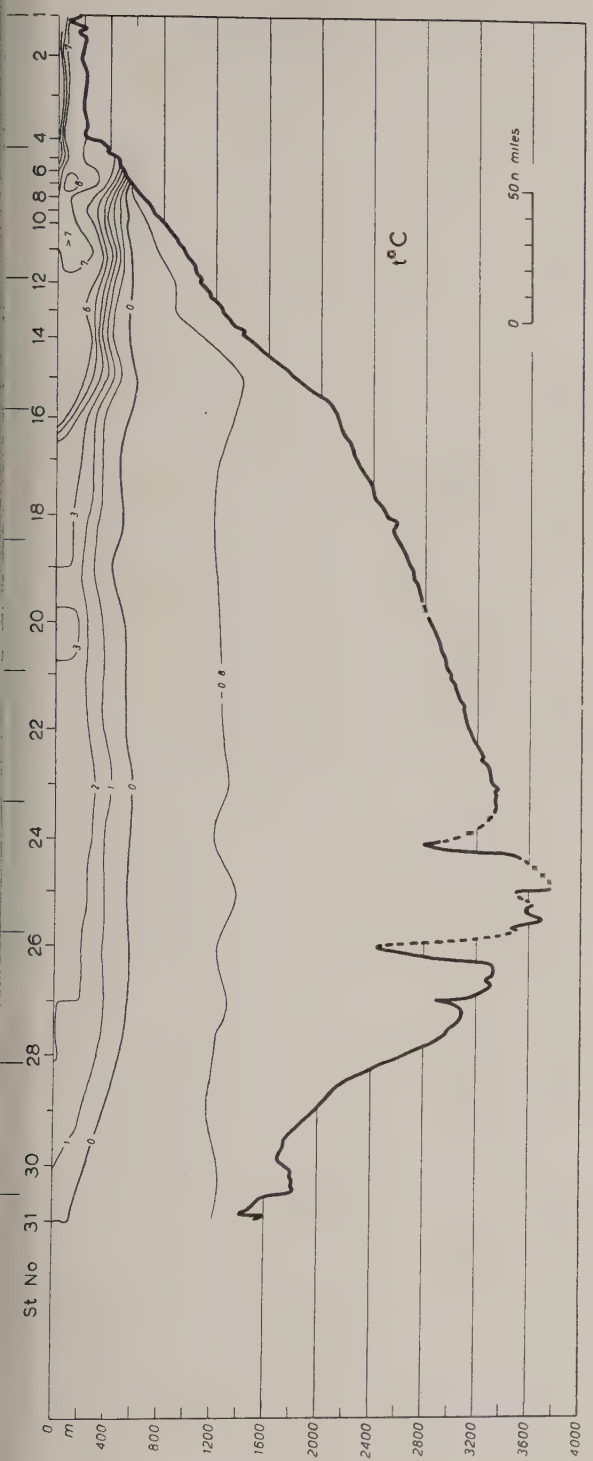
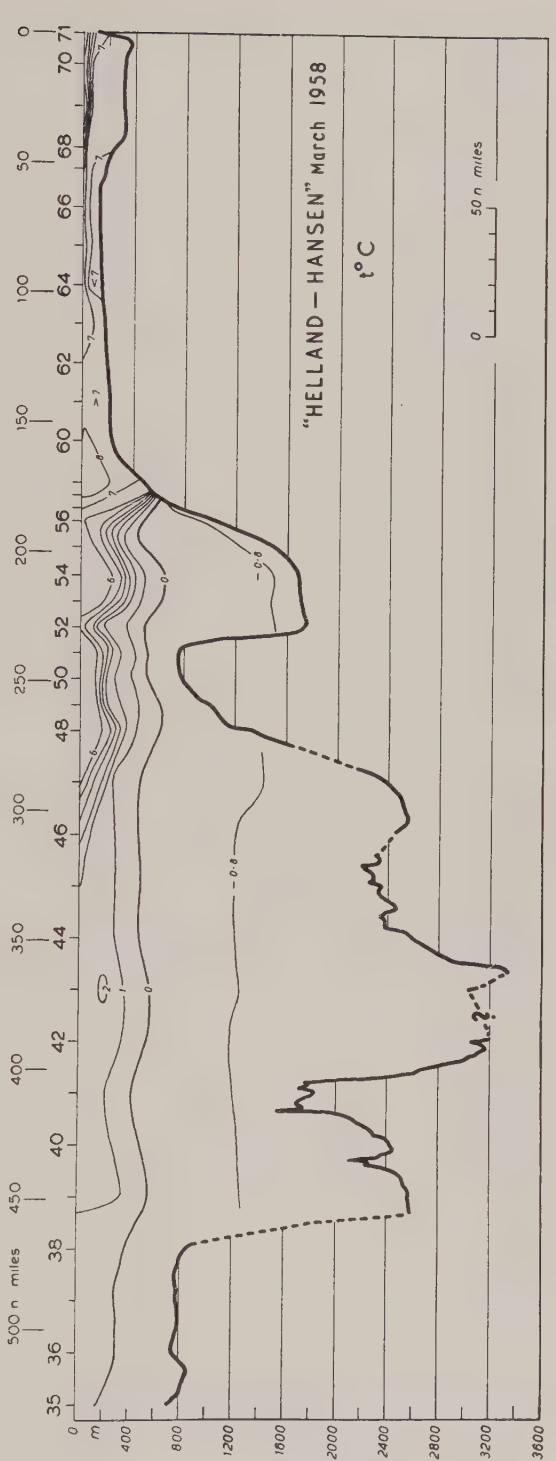


Figure 2a.



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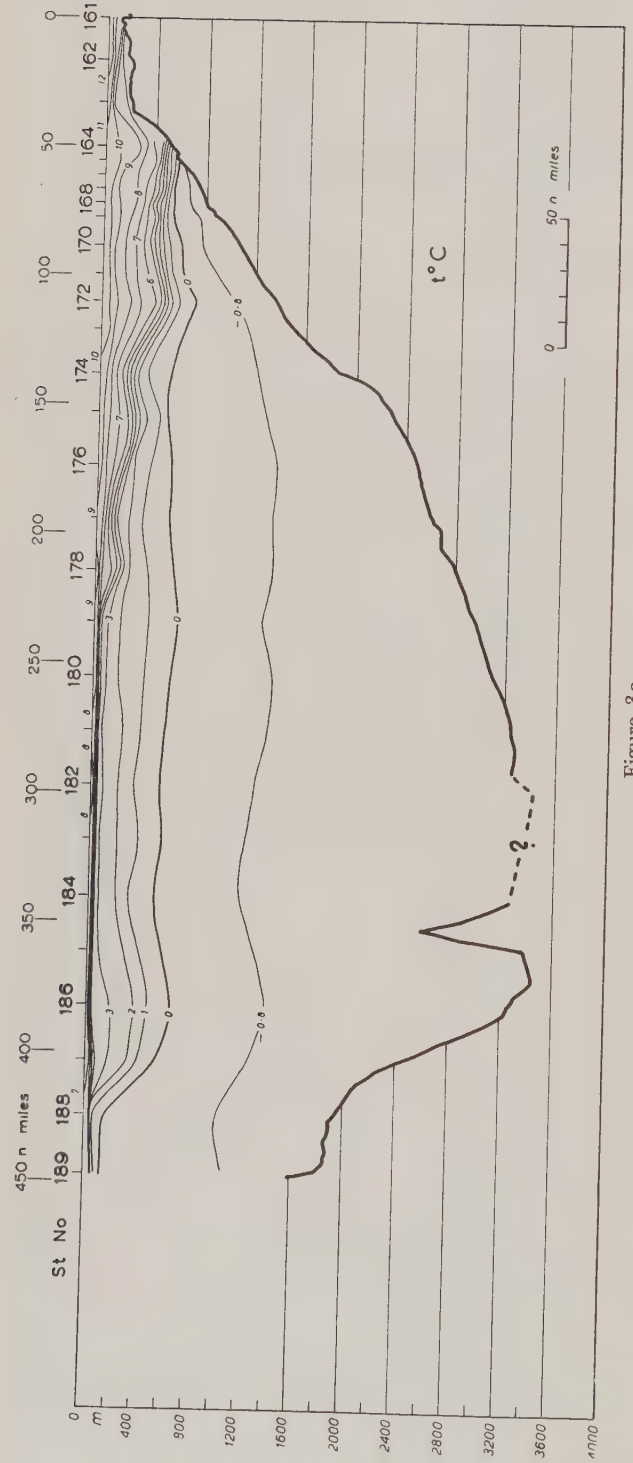
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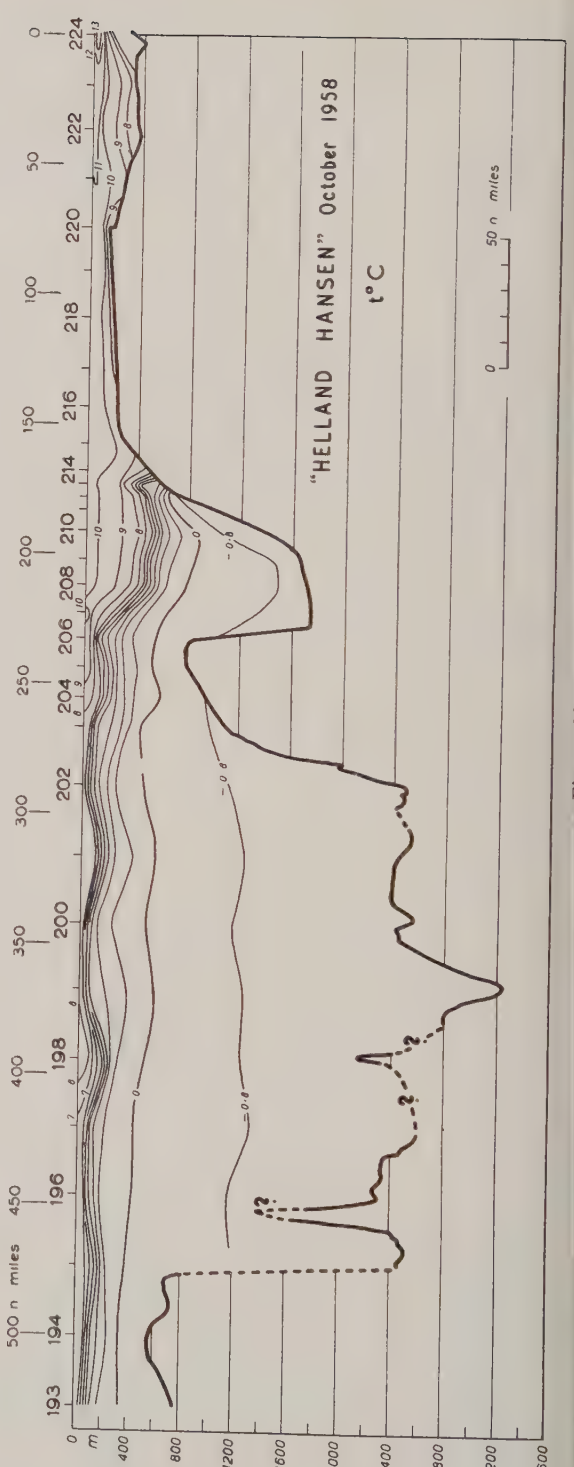
Figure 3a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ections were to be occupied also by Soviet ships nd/or ships from the Norwegian Fisheries Directorate. It was reckoned that such repetition of the ections might give useful information on the variability of the hydrographic conditions. On the cruise n March, 71 hydrographic stations were worked uring the period 13. to 22. March. Salinity and emperature were observed, and also oxygen at a ew stations. On the cruise in October, 64 stations vere occupied during the period 16. to 26. October. The same elements were observed as in March. Echooundings were made throughout both cruises, and a st of soundings is available for those interested. The oundings from the March cruise are considered to e especially valuable because of the good position ixings obtained on that cruise. The analysis of the esults will, of course, be made in connexion with he whole Polar Front survey. In this report we shall nly show the distribution of temperature on the ections: it appears in Figures 2 and 3. The northern ection is shown in the uppermost parts of the igures. In the eastern (right-hand) parts of the ections, the usual wedge-like shape of the Atlantic vater area is discernible from the course of the sotherms. The isohaline of 35 $^{0}/_{00}$ nearly coincides vith the 4° isotherm, except in the western part of he October sections. There is a considerable differnce between the extent of Atlantic water in the orthern section in March and in October. In March, he Atlantic water (salinity above 35 $^{0}/_{00}$) stretches 20 nautical miles out to sea from the banks, with a ross-sectional area of 69 km². In October, the listance is 190 nautical miles and the cross-sectional rea is 100 km². For the northern section in March, the volume transport has been computed for that part of the section limited vertically by stations 4 and 17 (where the 35 $^{0}/_{00}$ isohaline ascends to the surface), and horizontally by the surface and the 1000 db. isobar, which has been used as the reference level in the part of the section where the depth exceeds 1,000 m. For the remainder of the section Helland-Hansen's (1934) method has been used, assuming zero current at the bottom. However, the significance of the computed transport value, viz. *3·1 mill. m³/sec.*, must be judged with due regard to the above-cited assumptions (Sælen, 1959). A special feature to be noted is the ascent of the cold bottom water on the continental slope off Norway, as demonstrated by the course of the isotherm for −0·8°C. This seems to be a permanent feature of all sections off the Norwegian south-west coast, and must probably have a dynamical significance. Finally, one should note the undulating form of the isotherms in the Atlantic water and in the transition zone between that water and the underlying bottom water: it is most clearly pronounced in the southern section of March. There are conflicting opinions on the cause for this occurrence (Sælen, 1959; Helland-Hansen and Nansen, 1909; and also Krauss, 1958).

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10.

The Atlantic Current and Water Masses in the Faroe-Shetland Channel and over the Iceland-Faroe Ridge during the IGY

By

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Introduction

Between June 1957 and September 1958, the Scottish fishery research ships "Explorer" and "Scotia" took part in the Polar Front Survey investigations sponsored by the International Council for the Exploration of the Sea as an integral part of the International Geophysical Year oceanographical programme. In addition to work around Iceland, eleven cross-sections of the Faroe-Shetland Channel, with, on four occasions, north-westerly extension of the more southerly cross-section into and across the region of the Iceland-Faroe Ridge, were accomplished as detailed in Table 1 and illustrated in Figures 3—13. Figure 1 shows the geographical locus of the cross-sections.

By the good offices of Norwegian colleagues on their research ship, "G. O. Sars", an additional section, number 12, was done in December 1958 and has been considered along with the Scottish ones (Figure 14).

Only temperature and salinity distributions are here considered; oxygen and phosphate distributions, from observations at selected depths, will be treated elsewhere.

The Atlantic Current

In terms of volume transport and in the unit of cubic kilometres per hour (km^3/hr), the intensity of the Atlantic Current through the Faroe-Shetland Channel, as assessed along each of the above 12 cross-sections during the IGY, is given quantitative expression in Table 1.

The volume transport figures of Table 1 were derived exactly as described by one of us in previous work of the same kind (Tait, 1957). The paired values, considering the separation of the two sections in time, and except perhaps for the first pair, are at least reasonably near to each other and thus mutually corroborative one of the other.

Table 1. Volume transport of the Atlantic Current in the Faroe-Shetland Channel, through the hydrographic sections, (a) Faroe Bank to Butt of Lewis, and (b) Faroe Islands to Shetland, during the IGY

Inclusive dates of sections Day/Month/Year		Volume transport km^3/hr	
(a)	(b)	(a)	(b)
14-19/6/57	20-21/6/57	16·7	21
4-6/9/57	19-20/9/57	7·8	7·2
29/11-1/12/57	—	13·8	—
16-22/3/58	12-14/4/58	4·5	3·1
31/5-4/6/58	18-19/6/58	11·1	9·1
20-21/9/58	16-17/9/58	18·2	18·2
—	15-16/12/58	—	20·1

It seems clear that the International Geophysical Year both began and ended with extraordinarily high intensity of the Atlantic Current through the Faroe-Shetland Channel, the assessments for the latter half of June 1957 and mid-December 1958 ranking almost with the highest of 69 similar assessments made between the years 1927 and 1952 inclusive (Tait, 1957).

Rapid recession of the 1957 mid-summer high intensity of flow is implicit in the assessment of only about 7·5 km^3/hr in September 1957. This value corresponds closely to the mean and median values of the above 69 assessments. Within the next quarter year the intensity of the Current had apparently almost doubled, again however to recede, some three to four months later, to approximately the lower quartile of previous assessments (Tait, 1957, p. 51).

The subsequent volume transport computations indicate resurgence of the Atlantic Current through the Channel from the early summer of 1958, through the autumn, to what was probably a maximal value of about 20 km^3/hr in mid-December.

In the form of a curve, taking the means of the paired values in Table 1, Figure 2 illustrates the progression of these events over the period of the International Geophysical Year, assuming smoothly progressive changes between the several assessments.

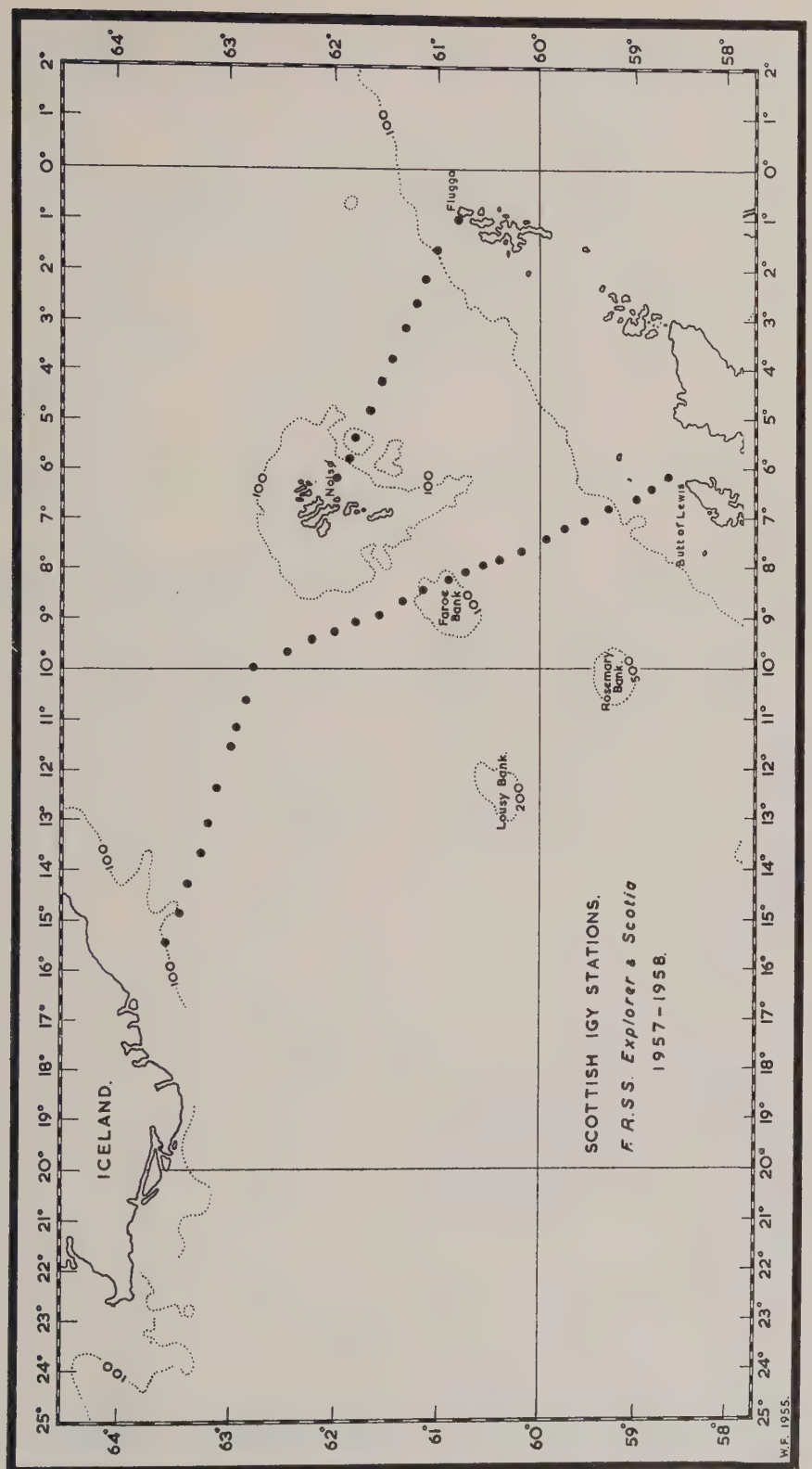

ICELAND.
Faroe Bank
Rosemary Bank
Louisy Bank
Butt of Lewis
Fluggo
SCOTTISH IGY STATIONS.
F.R.S.S. Explorer & Scotia
1957-1958.
W.F. 1955.

Figure 1.

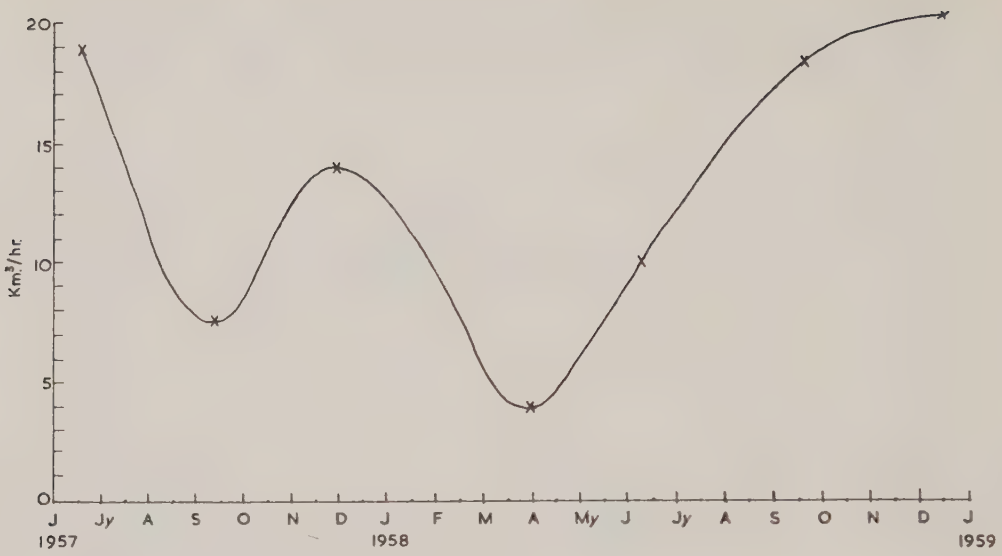


Figure 2.

The Water Masses

There is nothing out of the ordinary in the core boundary salinities and maximum nuclear salinities of the oceanic water mass as shown in Table 2 for the period of the IGY. Over a very much longer period it has been shown that Atlantic core boundary salinities of from 35·25 ‰ to 35·45 ‰ may occur on these Faroe-Shetland Channel cross-sections with correspondingly low and high maximum nuclear salinities, but none so high as the two bracketted figures in Table 2. These would appear to be significant of the presence of Gulf of Gibraltar water within the oceanic water mass, that is, in the month of June in both the years 1957 and 1958.

It is only when the sections are examined individually and compared with one another that differences emerge which more or less correspond with the differences in volume transport of Table 1.

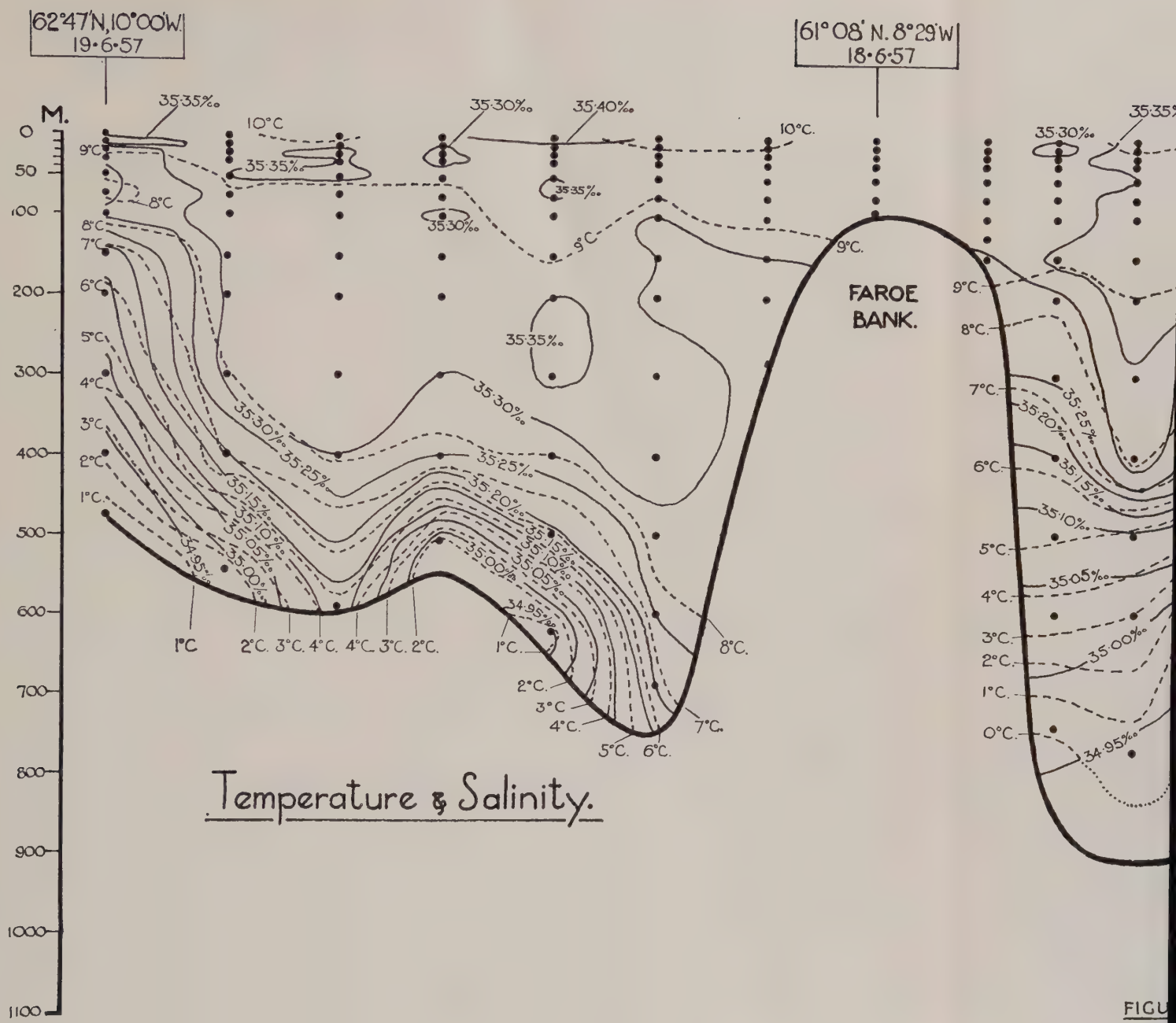
Temperature and salinity distributions on the first of the Scottish IGY sections across the southmost reach of the Faroe-Shetland Channel, namely, that run between the 14. and 19. June 1957 from the Butt of Lewis obliquely across the Wyville Thomson Ridge, over the north-eastern part of Faroe Bank to an intersection with longitude 10°W almost below latitude 63°N, are shown in Figure 3.

The main Atlantic Current core, extending from the continental shelf north-westwards to the Wyville Thomson Ridge, does not break surface as, from previous work, it normally does, but lies between about 40 and 100—150 metres. It embraces two Gulf of Gibraltar water nuclei, one of 35·54 ‰ salinity at 75 metres over deep water and the other, 35·67 ‰ salinity, on the bottom in just over 100 metres on the outer continental shelf. There are two detached portions of the Atlantic core as defined by the 35·40 ‰ isohaline, one of which breaks surface at a single station over the outermost part of the main subsurface core and encloses a Gulf of Gibraltar water nucleus of 35·50 ‰ at 20 metres depth. The other detached portion lay deep, between 475 and 650 metres, on the continental slope.

As embraced by the 35·35 ‰ isohaline it is evident that the oceanic water mass on this section was both laterally very extensive and penetrated deeply, to about 750 metres on the continental slope. Part at least of the explanation of this deep penetration is indicated by the shapes of the 35·35 ‰ and succeeding lower isohalines and the associated isotherms at the station immediately north of the Wyville Thomson Ridge. As is evident from scrutiny of the next cross-section of the channel, taken a few days later between the Faroe Islands and Shetland, these

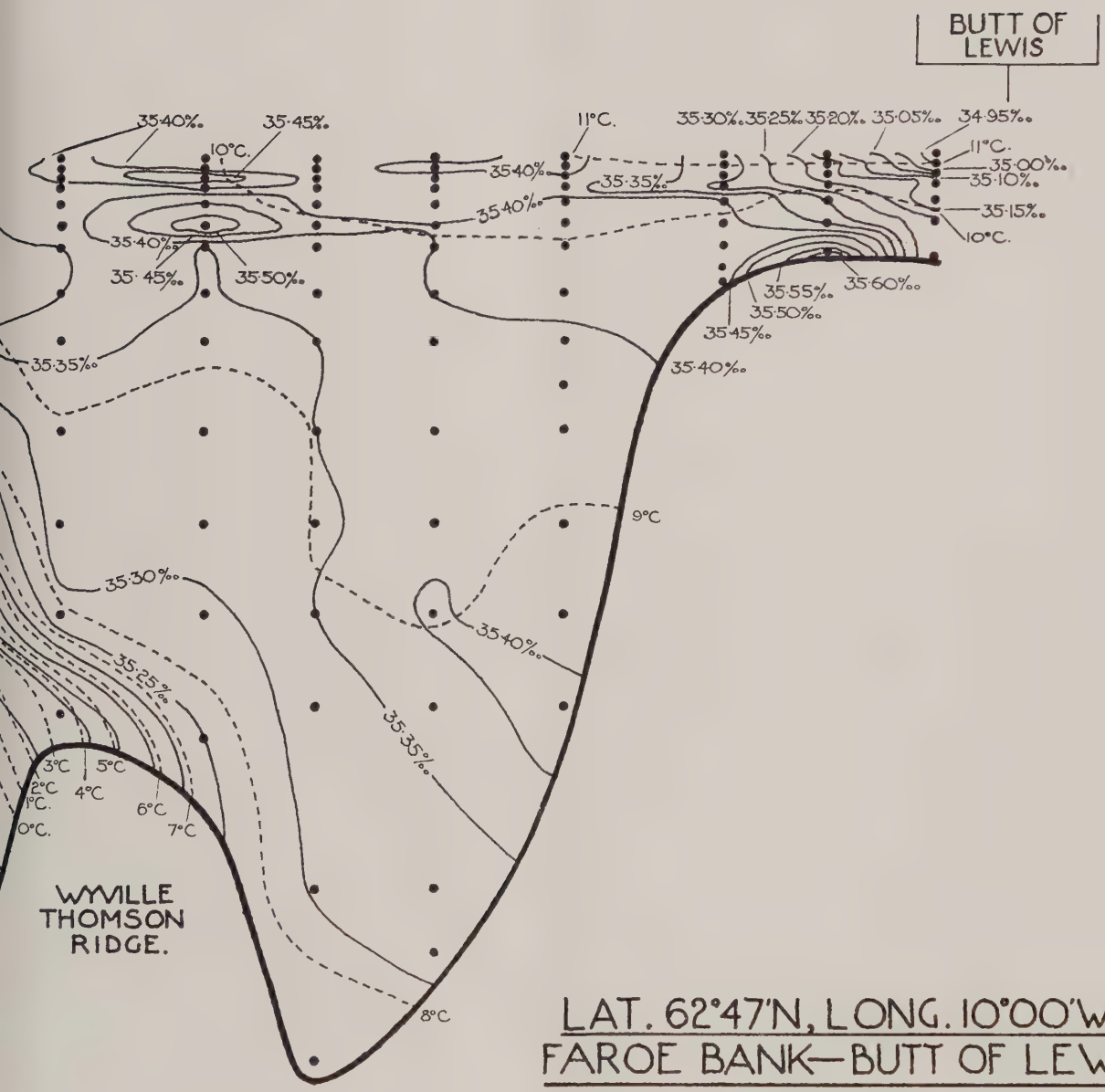
Table 2. The Atlantic Current cores and maximum nuclear salinities in the Faroe-Shetland Channel during the IGY

Year	Month	Faroe Bank/Butt of Lewis		Faroe/Shetland	
		Core boundary salinity (‰)	Max. nuclear salinity (‰)	Core boundary salinity (‰)	Max. nuclear salinity (‰)
1957	June.....	35·40	35.44 (35.67)	35·35	35·43
	September .	35·40	35·45	35·35	35·39
	Nov.-Dec...	35·40	35·44	—	—
1958	March.....	35·35	35·43	—	—
	April.....	—	—	35·35	35·44
	June.....	35·40	35·44	35·40	35·44 (35·59)
	September .	35·40	35·44	35·40	35·47
	December..	—	—	35·40	35·40



Temperature & Salinity.

FIGU



LAT. 62°47'N, LONG. 10°00'W. — FAROE BANK—BUTT OF LEWIS

F.R.S. 'SCOTIA'

14 - 19 JUNE 1957.

apes signify the intrusion southwards into the annel of a narrow current from the north, stemming from Helland-Hansen and Nansen's subsurface rrent of intermediate Arctic water on the northern pe of the Faroe-Iceland Ridge. On the section esently under examination only bottom Norwegian a water is indicated by the temperatures and salities recorded in the "toe" of the channel between e Wyville Thomson Ridge and Faroe Bank.

North of the Faroe Bank the bulk of the oceanic ater mass was contained within the 35·30 ‰ isoline, again lying deeply to a maximum of 400—0 m, with only a slight indication at one station a very thin superficial layer of 35·40 ‰ salinity ater, and two subsurface samples in excess of ·35 ‰ salinity. This oceanic mass overlaid two parate and distinct cold water masses (< 1°C) deep Norwegian Sea water. One of these lay in er 600 metres almost immediately north of Faroe nk and was probably continuous, via the north the bank, with the similar bottom water registered the "toe" of the Faroe-Shetland Channel between e bank and the Wyville Thomson Ridge. The her, however, on the bottom, between 400 and 600 etres at the outermost station of the section on ngitude 10°W, while no doubt of similar origin, e. the deep waters of the Norwegian Sea, almost rtainly came by another route. The position of this ation was within the cold water bracket found by eele (1959) in the beginning of August 1958 as gnificant of cold deep water overspill of the Faroeeland Ridge from the north, and this was almost rtainly the route followed by the cold bottom water und on longitude 10°W, latitude 62°47′N in June 57.

The section between Nolsø, Faroe and Flugga, etland, worked on 20.—21. June 1957 (Figure 4), ows, in its temperature-salinity distributions, a rearkable feature very closely resembling that of a milar diagram for the same section in May 1937 Tait, 1957, p. 132). The oceanic water mass is alost completely cloven in two about mid-section y the intrusion of what the recorded salinities ow to be intermediate Arctic water from the north. he extent of this incoming cold water mass is indited by the closed 34·90 ‰ isohaline on Figure 4, nbracing water of uniform salinity of 34·88 ‰ d, for the most part, sub-zero temperature, this ater mass being embedded, as it were, in bottom orwegian Sea water of somewhat higher salinity. Note, however, that the small isolated cross-section of intermediate Arctic water between 100 and 00 metres in the vertical line of the cleavage regiered a minimum salinity of 34·85 ‰.) Hence also, a consequence of this cleavage of an intensely flowing oceanic water mass, the deep penetration of the latter, to 750 metres off the continental slope on the one side and to about 500 metres on the other, that is, on the Faroe shelf slope. Disruption of a 35·40 ‰-plus salinity core of the Atlantic current into three small parts, one surface and one bottom to the south-east of the cleavage, and the third subsurface at about 50 metres on the northern side of the divide, is no doubt similarly to be explained as a result of the turbulence caused by the cold water intrusion opposing the advance of a particularly strong and copious Atlantic Current (see Table 1).

The observations from a second IGY crossing of the Faroe-Shetland Channel over the Wyville Thomson Ridge, in the beginning of September 1957, are illustrated in Figure 5. The core of the Atlantic Current within a 35·40 ‰ salinity boundary is again subsurface (50—325 metres), the main oceanic water mass lies much less deeply than in June and is much less extensive laterally. Isothermal and isohaline trends north of the Wyville Thomson Ridge indicate considerable turbulence, but there is no evidence on this section of the intrusion of an intermediate Arctic water mass. Indeed there is only a very small cross-sectional area, apparently divided into two parts, of bottom Norwegian Sea water between the Wyville Thomson Ridge and Faroe Bank. The division and the apparent bulk between and around them of an admixture of oceanic and bottom Norwegian Sea water, which it has been proposed to call suboceanic water, suggest that the indicated disturbance was due to this cause, namely, the turbulent admixture of oceanic and bottom Norwegian Sea water masses. Note the isolation of a small, relatively high salinity, body of oceanic water far down (575—675 metres) on the Faroe Bank slope.

The evidence which was lacking on the above section for the intrusion of intermediate Arctic water into the Faroe-Shetland Channel in September 1957, as in June of the same year, is unmistakable in Figure 6, illustrative of the section overtaken on 19.—20. September between Faroe and Shetland. Except along the continental slope where the oceanic water mass reaches below 600 metres, evidently due to lateral pressure by the intruding cold water mass, intermediate Arctic water occupies almost the whole of the deep layers below about 500 metres to the bottom, with only a small residuum of bottom Norwegian Sea water isolated in a thin vertical layer clinging to the Faroe Shelf slope between about 750 and 1100 metres.

The main Atlantic Current core, 35·35 ‰—35·39 ‰ salinity, is once again subsurface, lying entirely below 75 metres to less than 350 metres on the continental slope, and completely covering the bottom of the continental shelf.

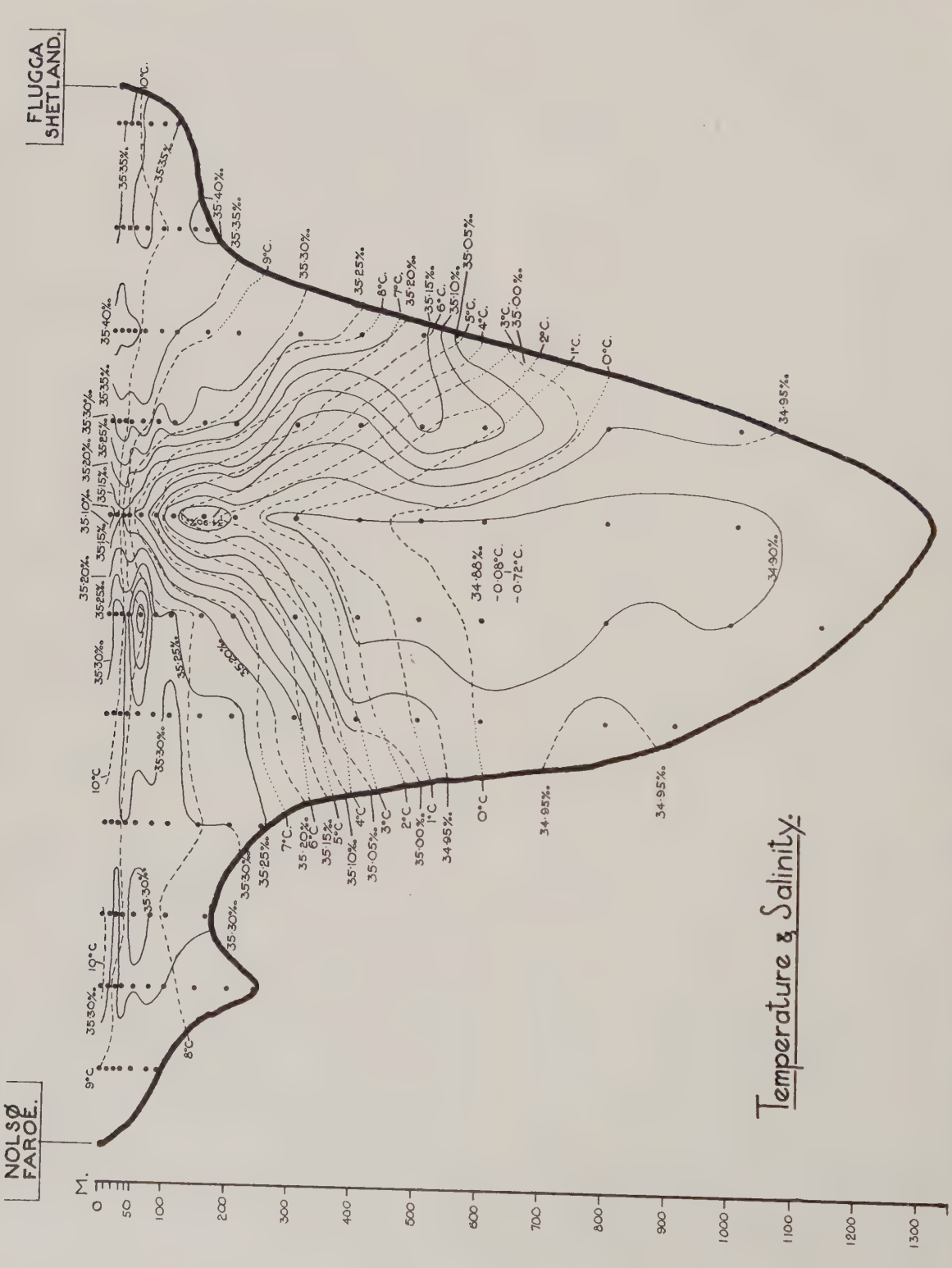


Figure 4. Nolsø, Faroe/Flugga, Shetland. F.R.S. "Scotia". 20.—21. June 1957.

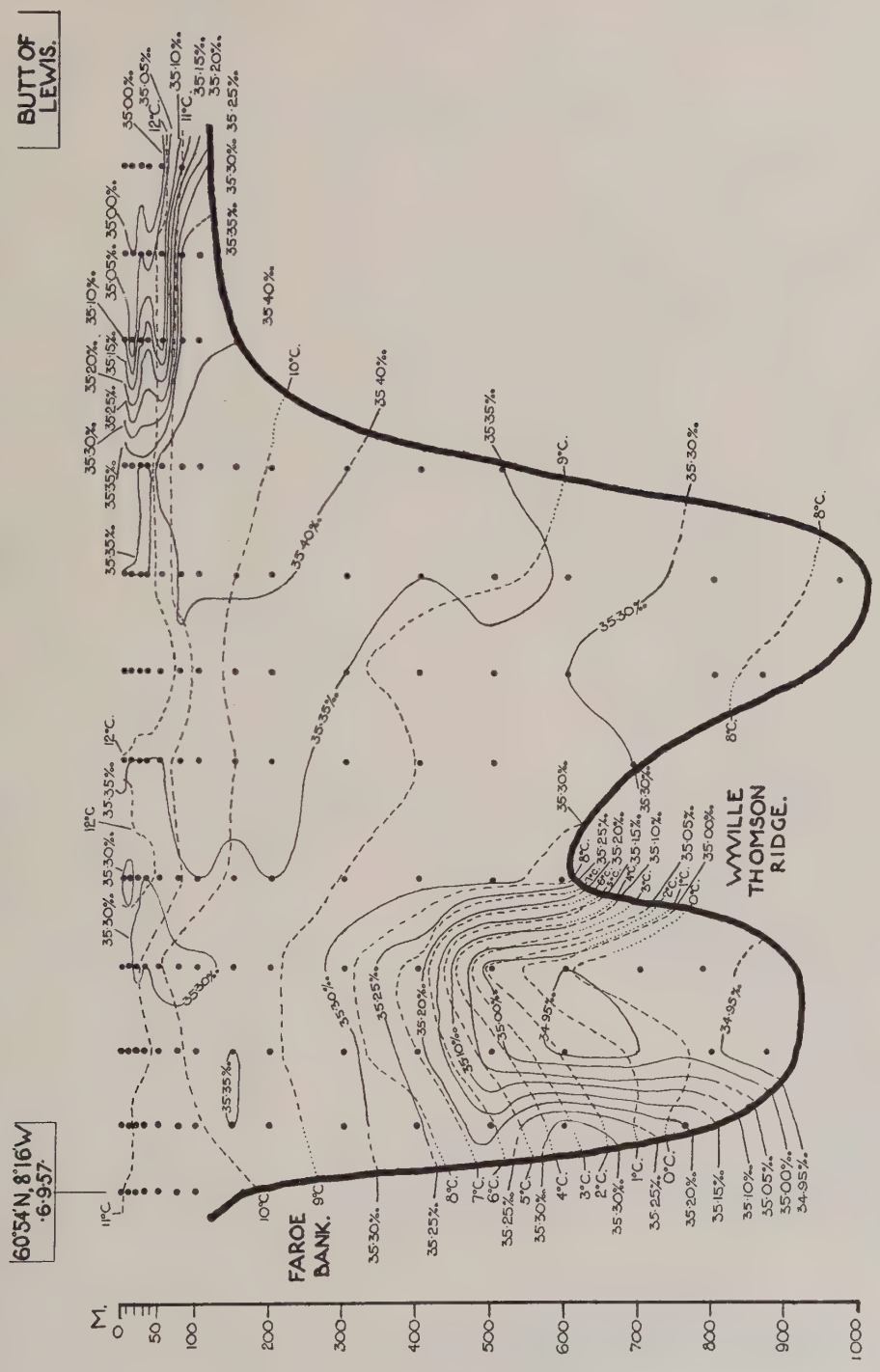


Figure 5. Faroe Bank/Butt of Lewis. F.R.S. "Scotia". 4.—6. September 1957.

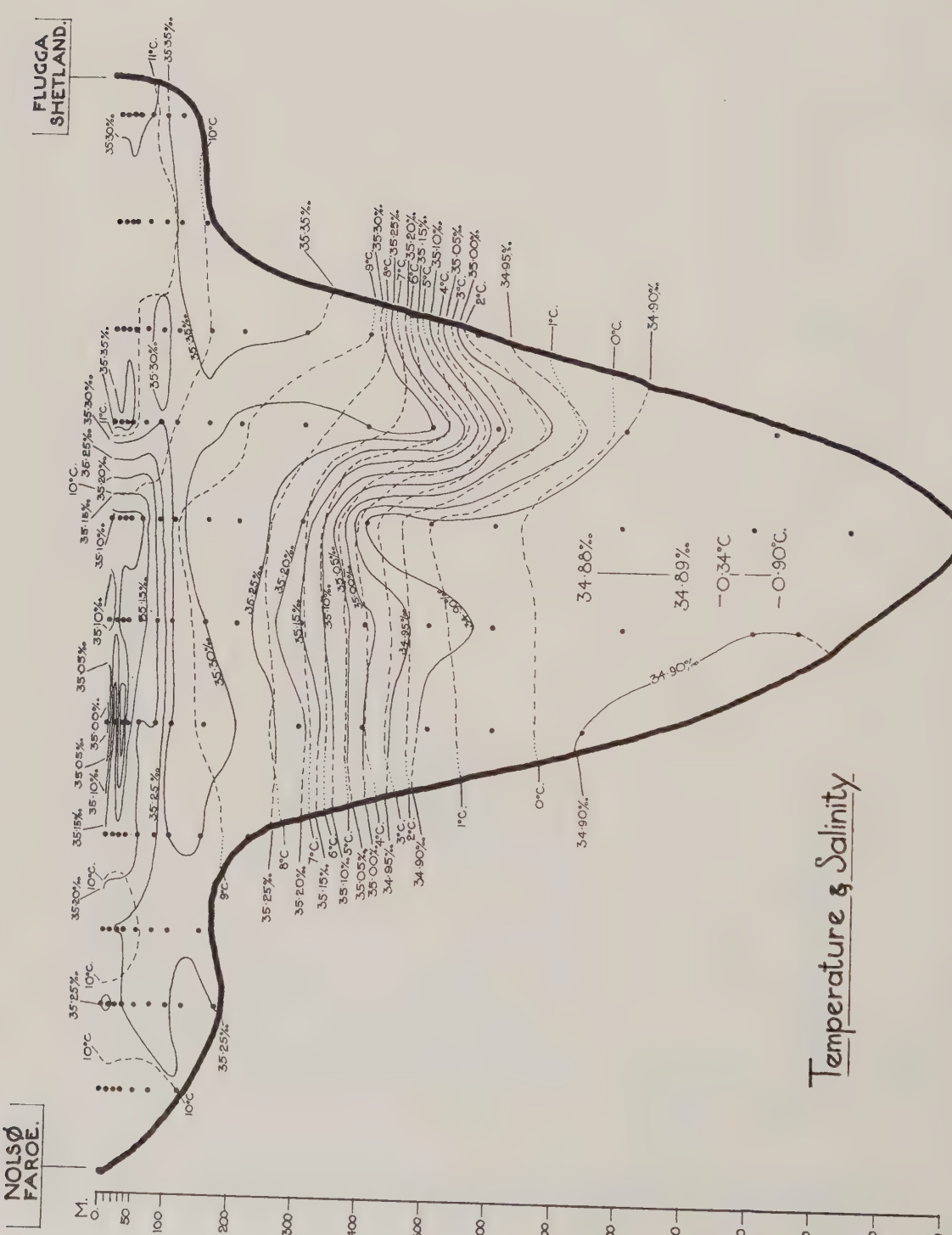
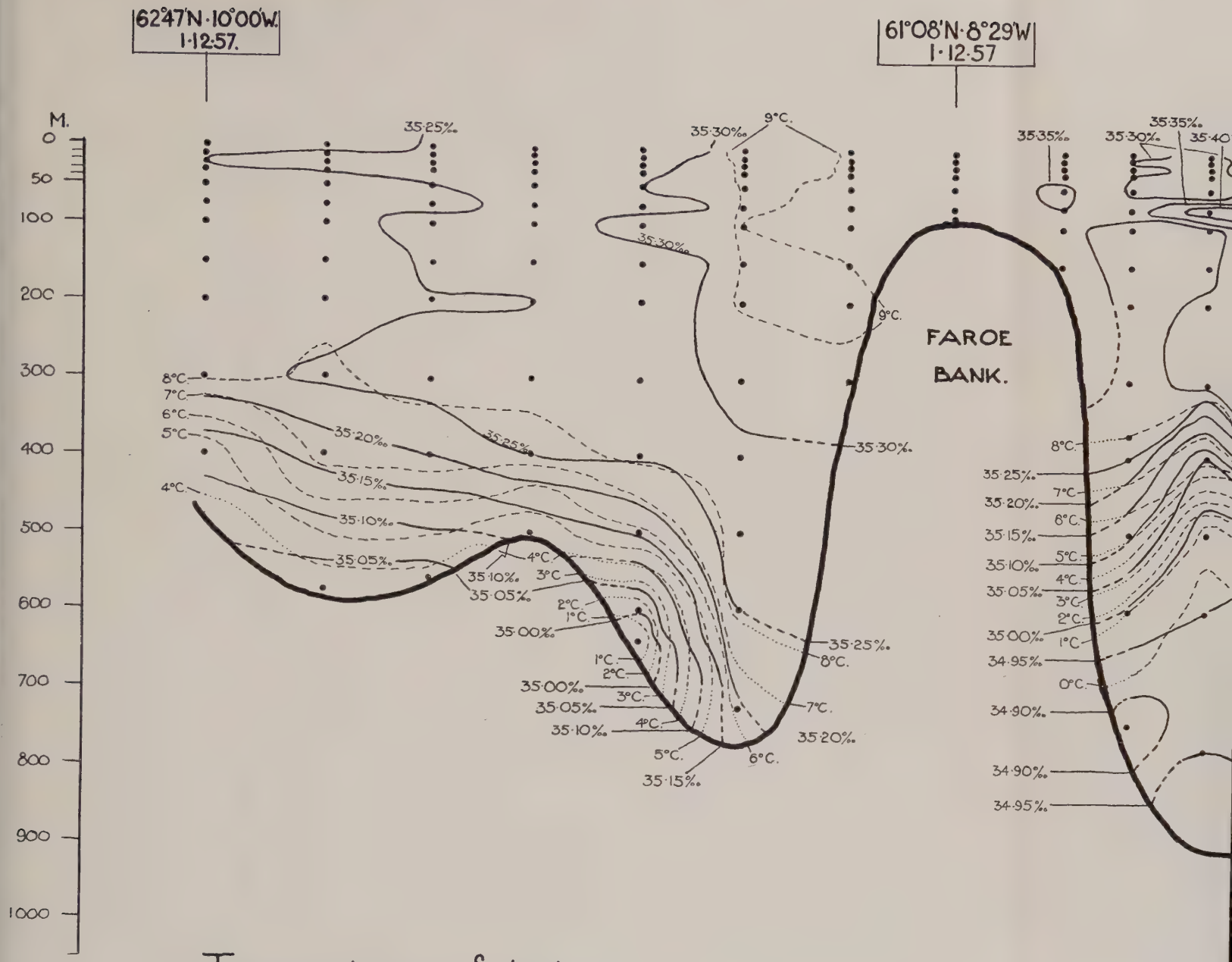
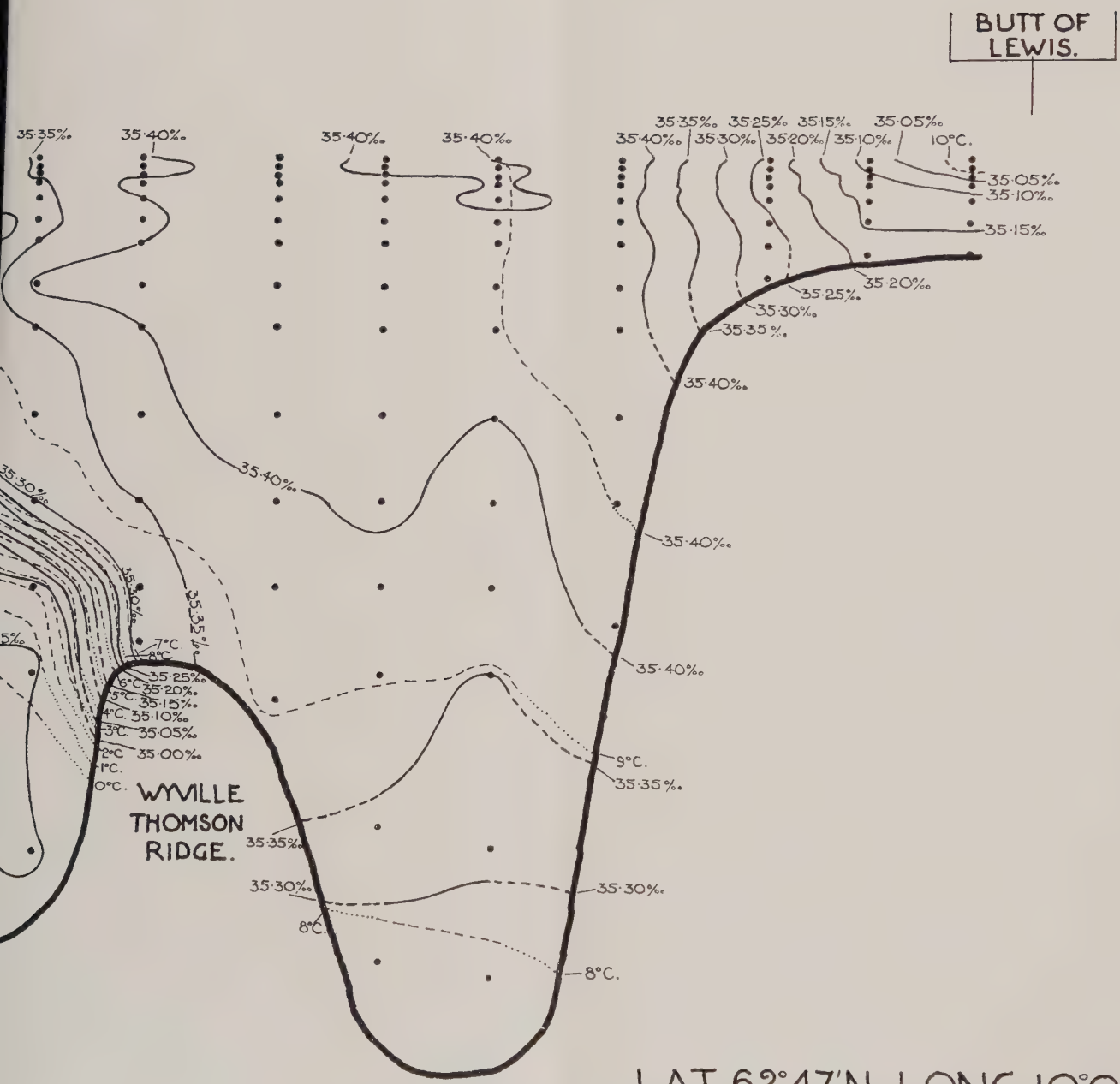


Figure 6. Nolsø, Faroe/Flugga, Shetland. F.R.S. "Scotia". 19.—20. September 1957.



Temperature & Salinity.

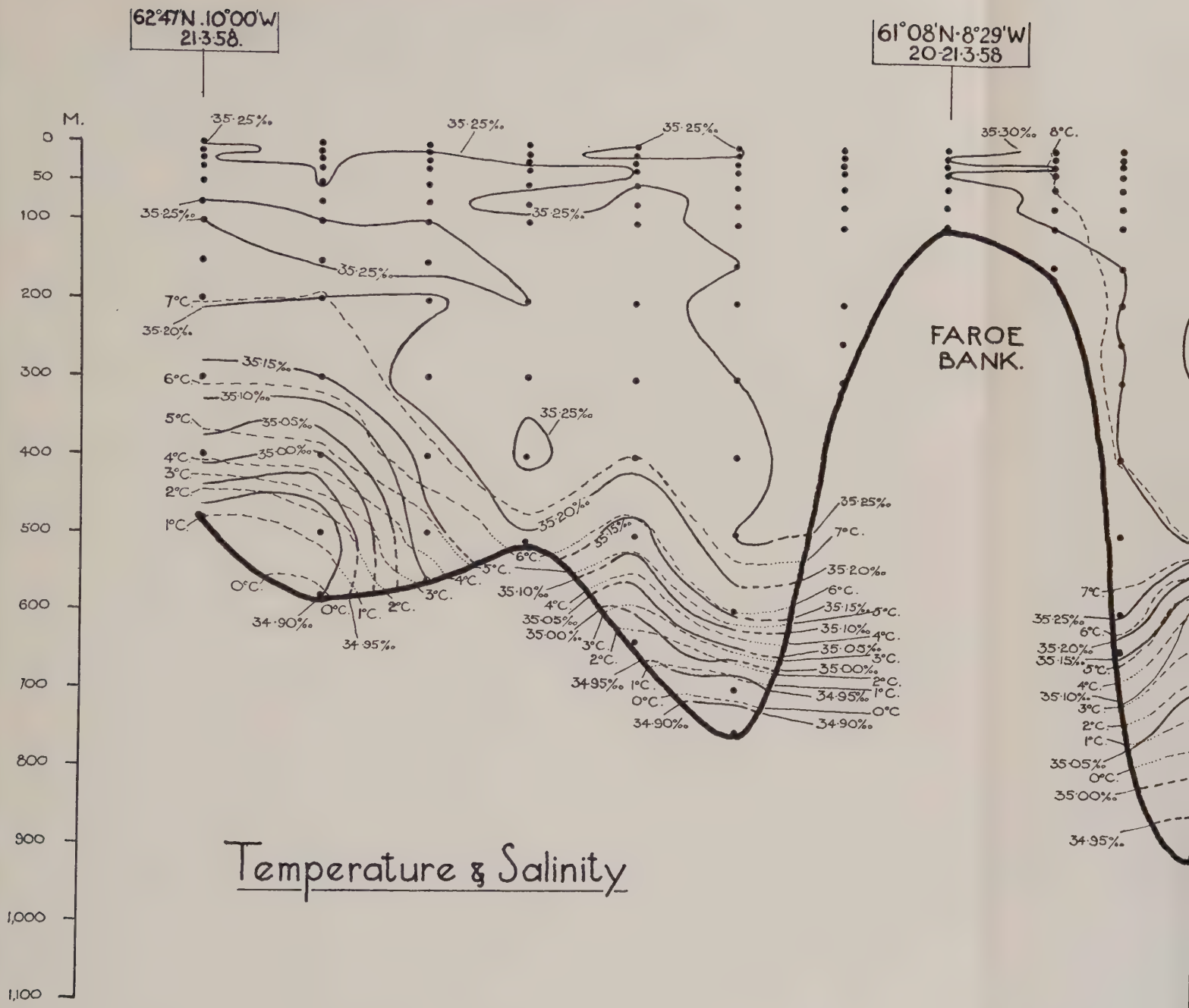
FIGURE 7.



LAT. 62°47'N. LONG. 10°00'W.
—FAROE BANK—BUTT OF LEWIS.—

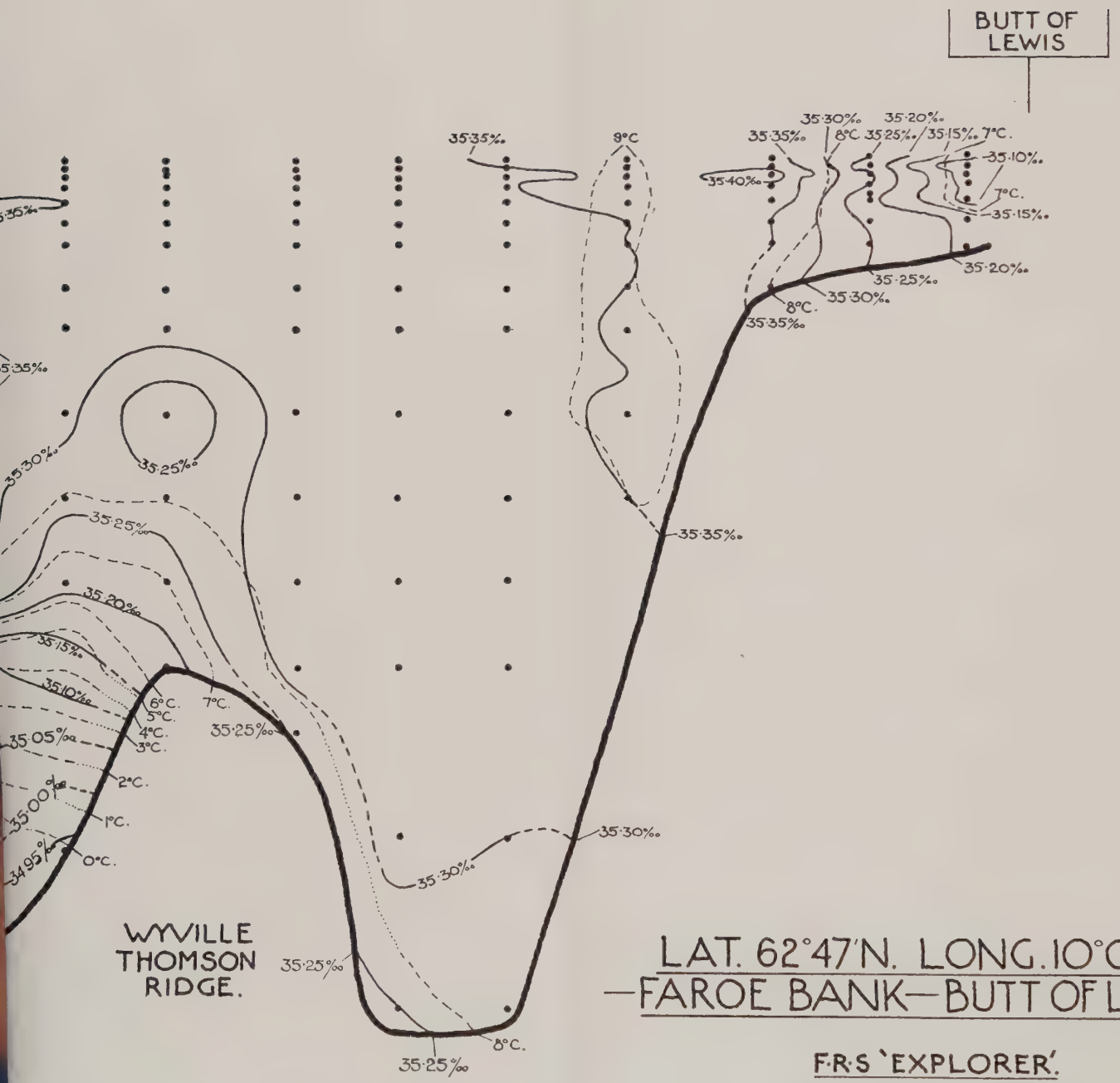
F·R·S·'EXPLORER.'

29 NOVEMBER–1 DECEMBER 1957.



Temperature & Salinity

FIGURE 8.



LAT. 62°47'N. LONG. 10°00'W.
—FAROE BANK—BUTT OF LEWIS—

F.R.S 'EXPLORER'.

16—21 MARCH, 1958.

Intrusion of a lower salinity water body between e main Atlantic core and a detached small surface rtion of the core, together with a marked lowering both temperature and salinity, the latter to below ·00 ‰, in the uppermost 100 metres of the section rth-westwards of the detached core sample, are dicative of colder fresher water intrusion from the rth of Faroe into the section.

For the third time in 1957 the Butt of Lewis to roe Bank section over the Wyville Thomson Ridge s accomplished between 29. November and 1. Dember, and for the second time extended to an intertion with longitude 10°W on the south-eastern pe of the Iceland-Faroe Ridge (Figure 7). The eanic volume transport through the Faroe-Shetıd part of this section, it may be recalled, was proaching twice that of September 1957 and, hough it need not necessarily be so, this is at once tirely consonant with the greatly increased crosstional area of the water mass within the 35·40 ‰ halines in Figure 7 as compared with Figure 5, e core of the Atlantic Current in Novembercember, moreover, breaking surface over a consirable length of the section and reaching bottom the continental slope from a depth of 250 metres about 575 metres.

The packing of the isotherms and isohalines beeen the Wyville Thomson Ridge and Faroe Bank, well as their shape in this region, is indicative of e characteristic differences between the northerlywing upper oceanic water mass and the southerlywing deep Norwegian Sea water mass, the latter parently including also some intermediate Arctic ter.

On the north side of Faroe Bank it is rather the therm of 9°C than any particular isohaline which fines the core of the oceanic water mass in this gion, this water mass as a whole, however, being distinctly inferior salinity to that of the Faroeetland Channel oceanic water mass borne by the ain Atlantic Current. And while evidence of at st the near presence of bottom Norwegian Sea ter of under 1°C appears again on the bottom the same station a little way north of Faroe Bank, on the June 1957 extended section, it is particuly to be observed that such cold water as apared on the bottom at the extremity of the extended tion in June and significant of overspill from e deep Norwegian Sea across the Iceland-Faroe dge, does not re-appear on the November-December tion.

Between the 16. and 22. March 1958, the Butt of wis/Wyville Thomson Ridge/Faroe Bank section s extended not merely to its intersection with ngitude 10°W (Figure 8), but from there was carried along the south-western slope of the Faroe-Iceland Ridge to within about 40 miles of the south-east coast of Iceland (Figure 8).

To deal with the Faroe-Shetland part of the section first, through which, according to Table 1, the oceanic transport was the lowest recorded on this section during the IGY, the restricted cross-sectional area and relatively inferior salinity of the Atlantic Current core, even if it reached from the sea surface to a depth of 450 metres on the continental slope, are therefore not surprising. On the other hand it is surprising in these circumstances to find the bulk oceanic water mass of over 35·30 ‰ so extensive and deep-reaching, especially on the southern part of the section, and to find oceanic water so far below the mean level (550 metres) of the Wyville Thomson Ridge on the north side of the ridge, namely, to over 800 metres. Very little bottom Norwegian Sea water appears in the still greater depths of this region in the toe of the Channel proper.

North of Faroe Bank the characteristically somewhat inferior salinity of the oceanic water mass there, compared with that passing through the Faroe-Shetland Channel, is again evident, but here we have, at the deepest station immediately north of the bank, sub-zero temperature water of a salinity (34·87 ‰) which suggests its origin from the intermediate Arctic water mass, no evidence of which was located on the south side of the bank. At the extremity of this part of the extension of the section, namely at the station on longitude 10°W, which is reproduced also in Figure 8, very cold (< 1°C) bottom water, presumably from over the other side of the Iceland-Faroe Ridge, is again in evidence at a depth of 450—500 metres. In addition to this feature reproduced on Figure 8, a further similar small body of cold (< 2°C) bottom water at the same depth was located beyond 11°W longitude, still on the higher slopes of the Iceland-Faroe Ridge near its summit, before, proceeding north-westwards, the bottom slopes steeply to depths in excess of 1400 metres. As can be seen from Figure 8, an oceanic water mass apparently continuous with that between Faroe and longitude 10°W, occupied the uppermost water layers of the entire extension of the section almost to Iceland, and apparently reached the great depth of 1,250 metres in the deepest part of this extension.

Figure 9 represents a fairly normal type of Faroe to Shetland section, showing, for mid-April 1958, a moderate cross-sectional core of the Atlantic Current breaking surface over an appreciable length of the south-eastern part of the section and in the main about 150 metres thick, but around a single station descending to over 300 metres without anywhere touching bottom. Penetration of the deeper layers by

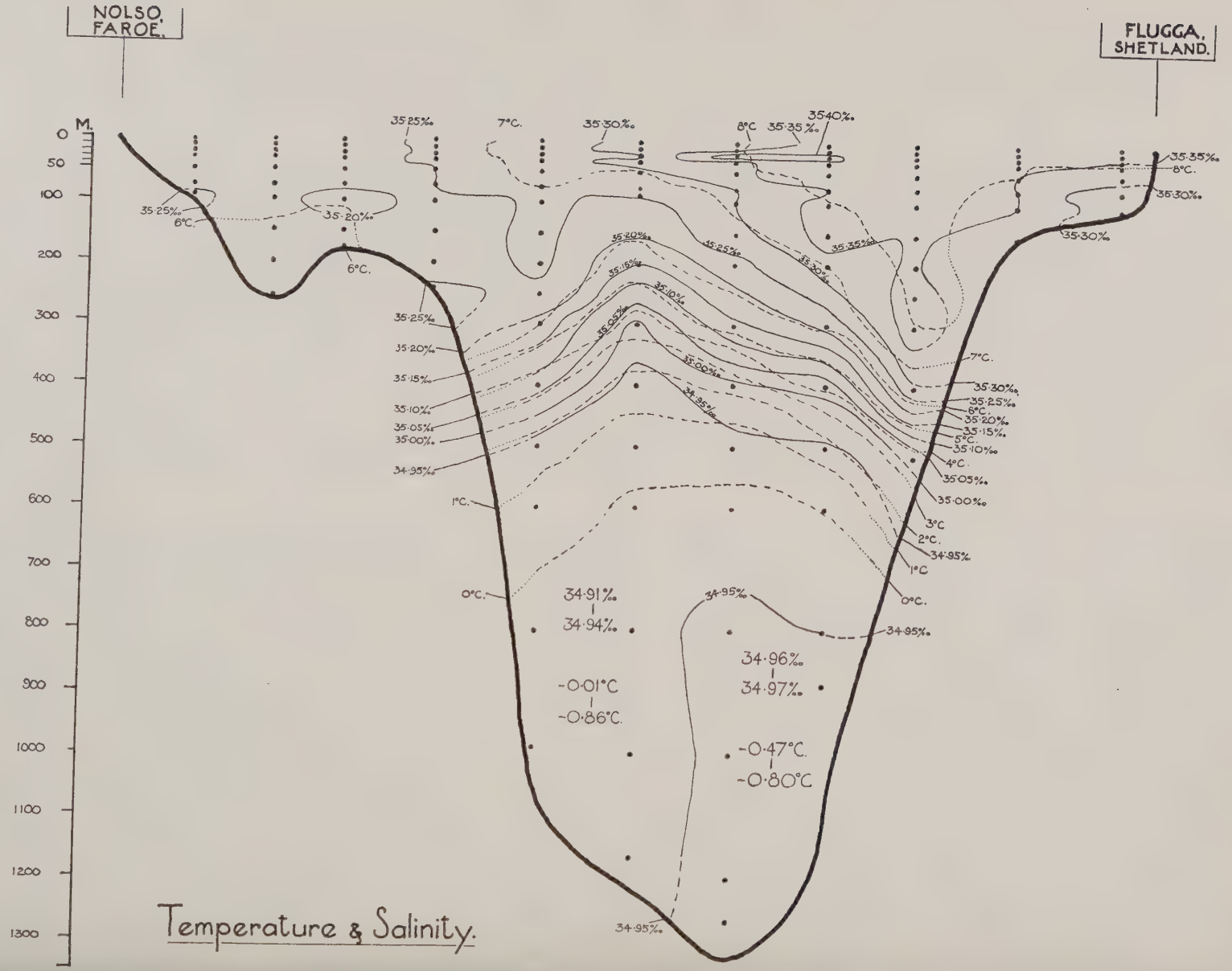
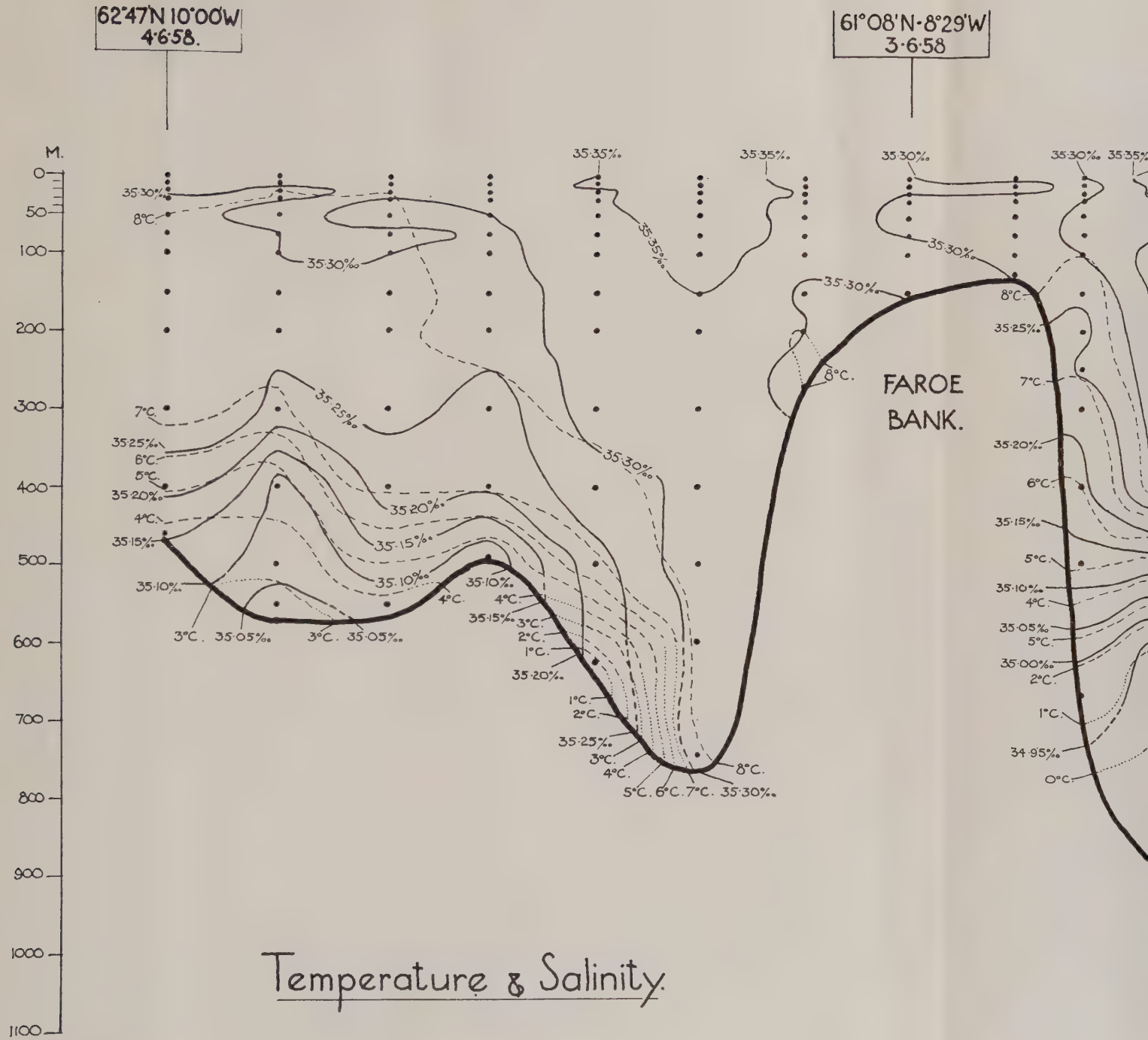
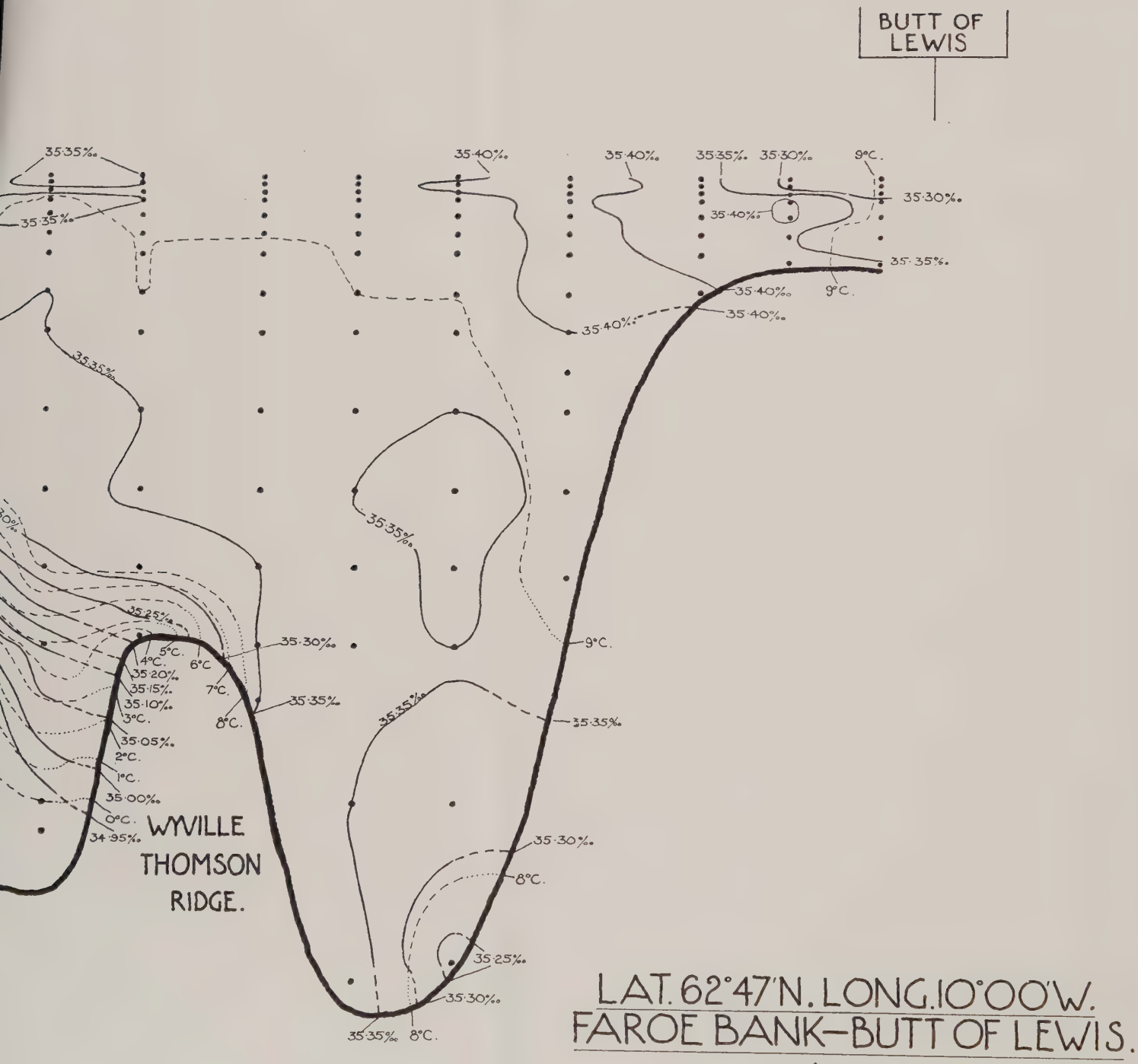


Figure 9. Nolsø, Faroe/Flugga, Shetland. F.R.S. "Scotia". 20.—21. June 1957.



Temperature & Salinity.

FIGURE 10.



LAT. 62°47'N. LONG. 10°00'W.
FAROE BANK–BUTT OF LEWIS.

F.R.S. 'SCOTIA'

31. MAY – 4. JUNE 1958.

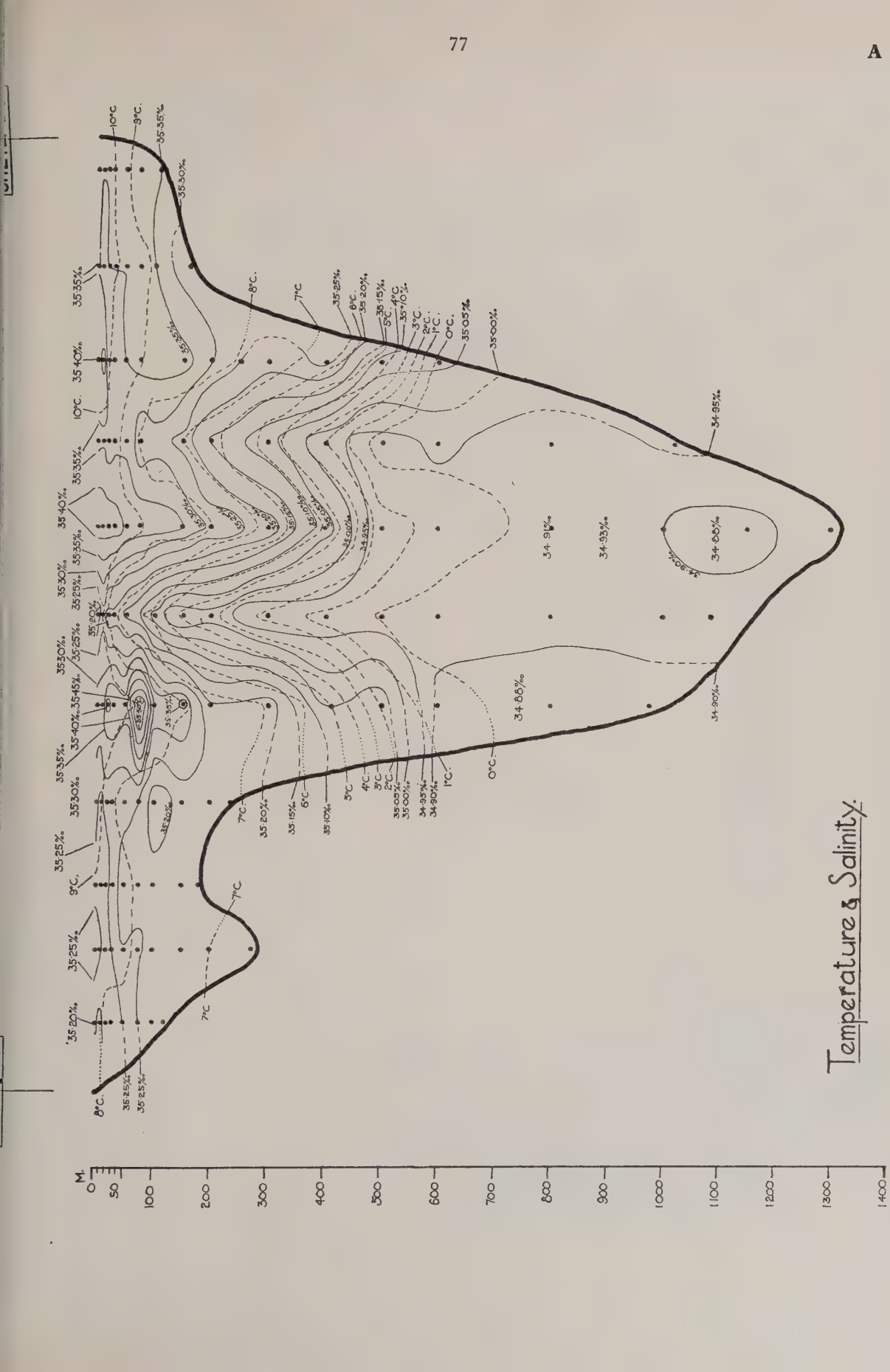


Figure 11. Nolsø, Faroe/Flugga, Shetland. F.R.S. "Explorer". 18.—19. June 1958.

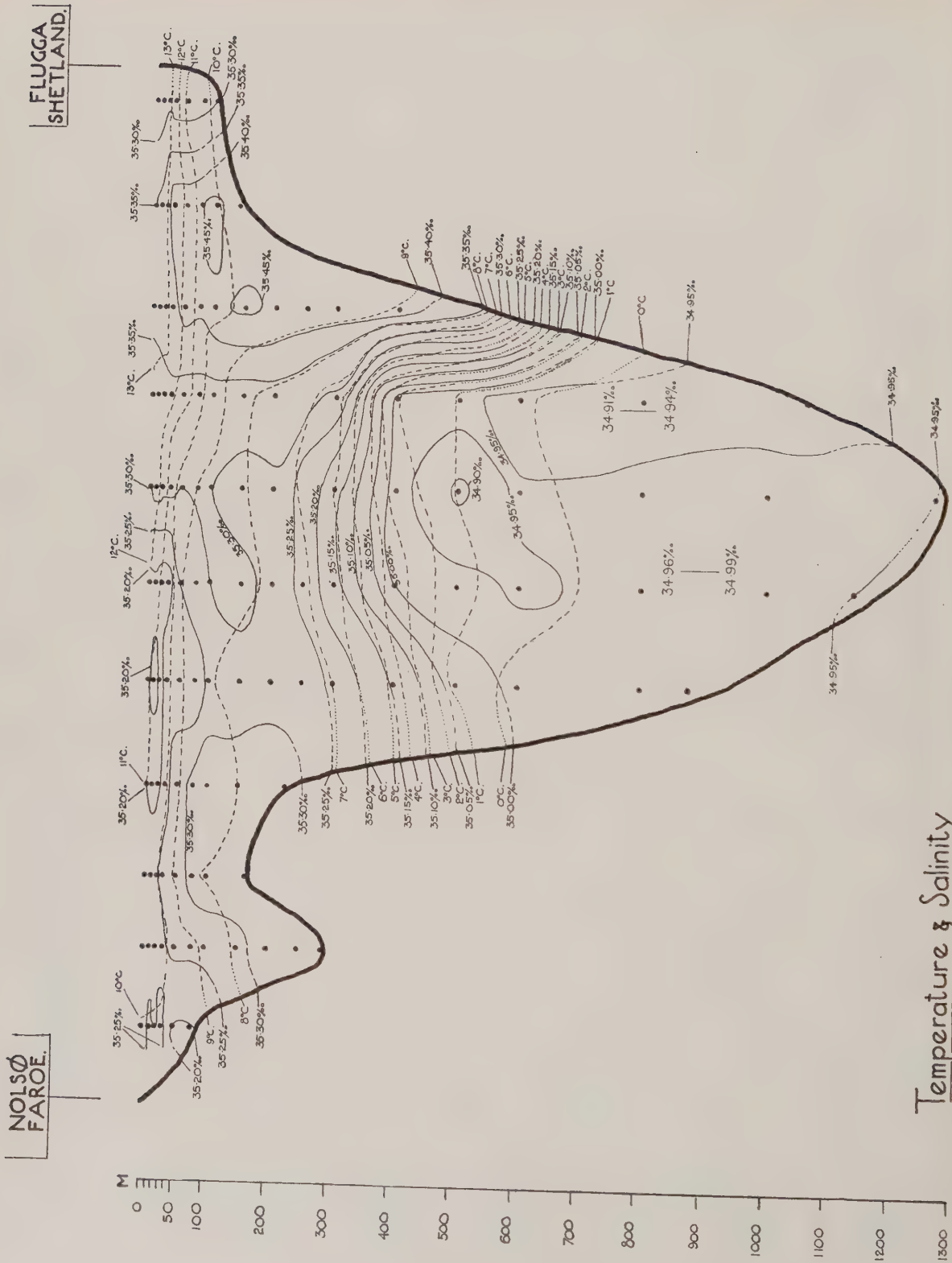
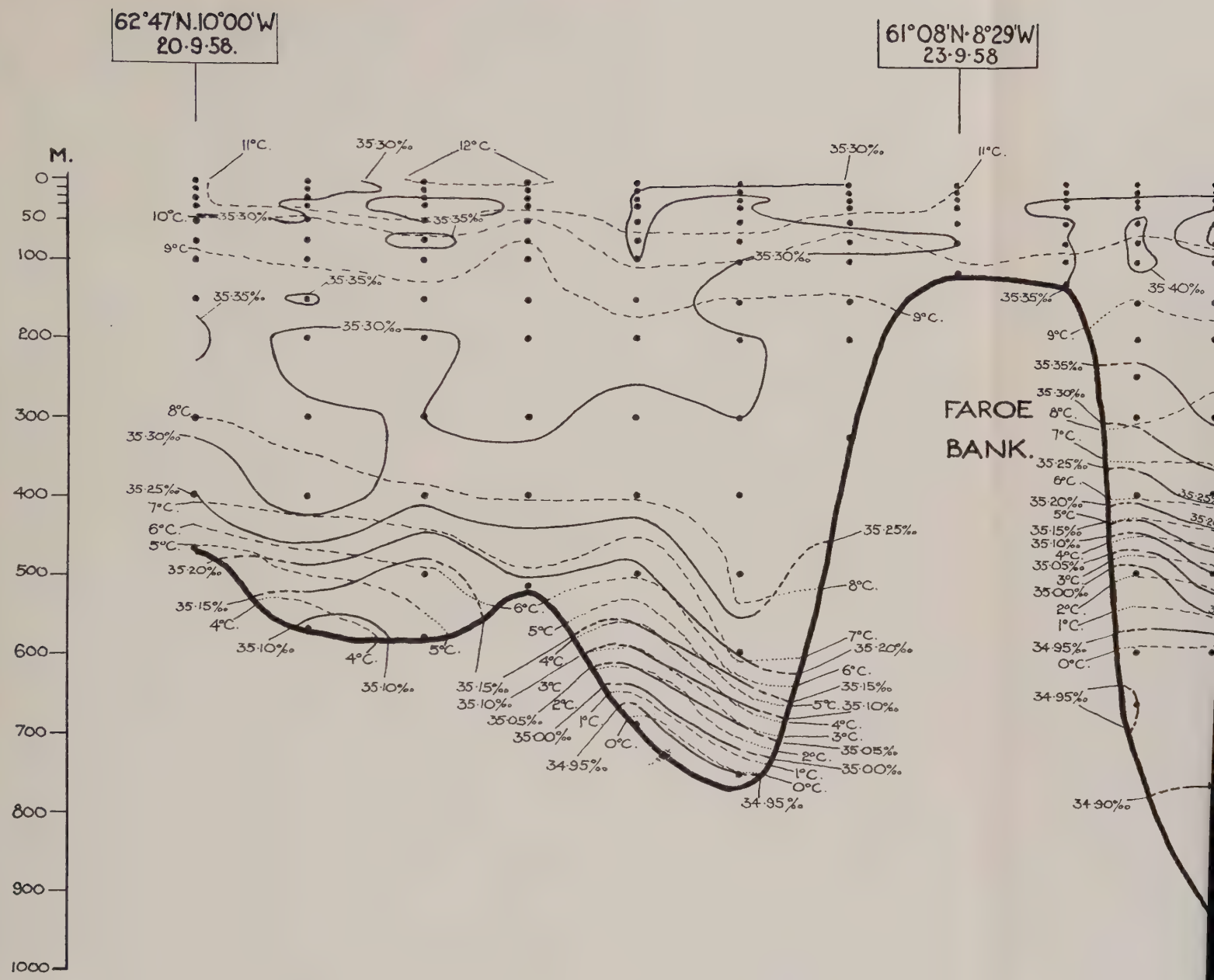
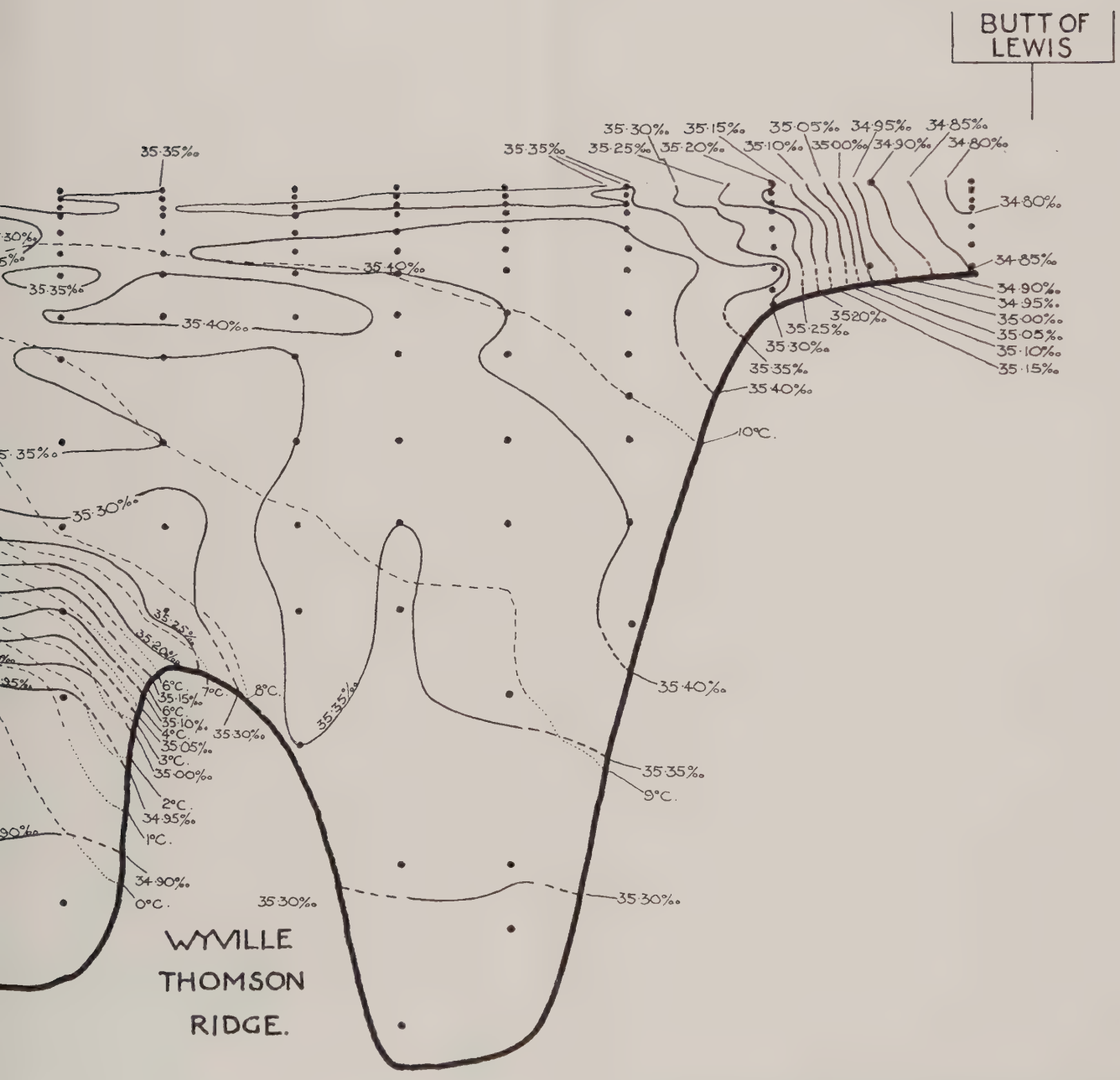


Figure 12. Nolsø, Faroe/Flugga, Shetland. F.R.S. "Explorer", 16.—17. September 1958.



Temperature & Salinity.

FIGURE 13.



LAT. 62°47'N. LONG. 10°00'W.

– FAROE BANK–BUTT OF LEWIS.

F.R.S. 'EXPLORER'

20-26 SEPTEMBER 1958.

ottom Norwegian Sea water of sub-zero temperature r the most part seems to have been at least fairly tense from 300 metres downwards. The isolation a body of sub-oceanic water (salinity 34·96 °/₀₀— 4·97 °/₀₀) of sub-zero temperature, below 750 metres the bottom in over 1,200 metres on the south-stern part of the section bespeaks considerable rbulence as between the oceanic and bottom Nor-egian Sea water masses prior to the accomplishment this section.

Passing to Figure 10 which represents the Butt of ewis/Faroe Bank/longitude 10°W section of 31. lay to 4. June 1958, a section of only a little over verage oceanic volume transport, it is to be ob-rved that while the central core of the Atlantic urrent represented by water in excess of 35·40 °/₀₀ linity is very restricted, although extending from rface to bottom on about the continental edge, the ceanic water mass contained within the 35·35 °/₀₀ ohalines is very extensive, both laterally and ver-cally, having deep water of high salinity (35·39 °/₀₀) ght to the bottom in over 1000 metres on the south de of the Wyville Thomson Ridge.

Oceanic water seems also to have penetrated deeply n the north side of the ridge, the 35·00 °/₀₀ isohaline aching a depth of 750 metres on its northern slope nd allowing, in cross-section, only a limited volume bottom Norwegian Sea water to reach the toe of ne channel below 600 metres depth.

Immediately north of Faroe Bank we have again ne occurrence, in about the same depth (650 metres), a small volume of cold bottom Norwegian Sea ater, in continuation probably of that on the other de of the bank in the Faroe-Shetland Channel, ut on longitude 10°W there is only evidence of ceanic water of temperature very little under 4°C n the bottom, no sign of overspill in this instance over ne Iceland-Faroe Ridge.

Once more, in Figure 11, we have the striking ature of Figure 4, cleavage almost from the surface ownwards by cold fresher water from the north of ne oceanic water mass pervading the Faroe to Shet-nd section of 18.—19. June 1958. This wedge of ld water was Norwegian Sea water which from a gh peak at 200 metres depth reached to the deep ttom of the section in over 1300 metres, except, etween 600 and about 1100 metres, for a body of ntermediate Arctic water (salinity 34·88 °/₀₀) clinging the Faroe Shelf slope between these levels, and a nall isolated portion of it between 1000 and 1200 etres in the middle of the deepest part of the section.

To the north of the divide the oceanic water ass contained a nucleus (salinity 35·59 °/₀₀) of Gulf f Gibraltar water at 75 m depth. South of the divide ere was no such anomaly and the core of the main Atlantic Current within the 35·40 °/₀₀ isohaline was exceedingly restricted.

The next of these Scottish IGY traverses of the important Faroe-Shetland Channel gateway to north-western European seas was overtaken between Shetland and Faroe on 16.—17. September 1958 and is illustrated in Figure 12. This, it may be recalled, was a section from which a remarkably high oceanic volume transport of over 18 km³/hr was computed. The core of the Atlantic Current on this particular section, contained within the 35·40 °/₀₀ isohaline, was completely subsurface and not particularly extensive in cross-section, although it included the bottom around the continental edge from depths of slightly over 100 metres on the continental shelf to about 450 metres on the adjacent slope. It included also two dated nuclear salinities of 35·46 °/₀₀ and 35·47 °/₀₀ respectively, but nothing conclusively indicative of Gulf of Gibraltar water.

The base of the oceanic water mass, as defined by the 35·00 °/₀₀ isohaline and attaining to depths of 600 metres and over 700 metres on the north-western and south-eastern slopes of the Channel proper respectively, was apparently raised in mid-Channel to less than 400 metres by the intrusion of a body of bottom Norwegian Sea water with a suspicion of intermediate Arctic water at the core of it. From the turbulence occasioned by this intrusion, the remainder of the deep water of the Channel comprised sub-oceanic (salinity 34·95 °/₀₀ to 34·97 °/₀₀) rather than bottom Norwegian Sea water, except for a columnar body of water which was definitely bottom Norwegian Sea water on the deep south-eastern part of the section, from 550 metres to bottom in from about 850 to 1200 metres.

Between the 20. and 26. September 1958, "Explorer" completed the fourth of the IGY sections from Iceland along the south-western slope of the Iceland-Faroe Ridge, over the Faroe Bank and the Wyville Thomson Ridge to the Butt of Lewis (Figure 13).

In the Faroe-Shetland Channel the Atlantic Current core bounded by the 35·40 °/₀₀ isohaline was once again subsurface, flowing between about 40 metres and from 250 to 575 metres on the continental slope, but none the less substantial in cross-sectional area (Figure 13). A detached portion of the core flowed alongside the main central current on its north-western flank between 100 and 175 metres. The oceanic water mass over the 35·35 °/₀₀ isohaline embraced the entire channel region laterally, and reached down to 650 metres on the south side of the Wyville Thomson Ridge. Bottom Norwegian Sea and, below it, a small body of intermediate Arctic water,

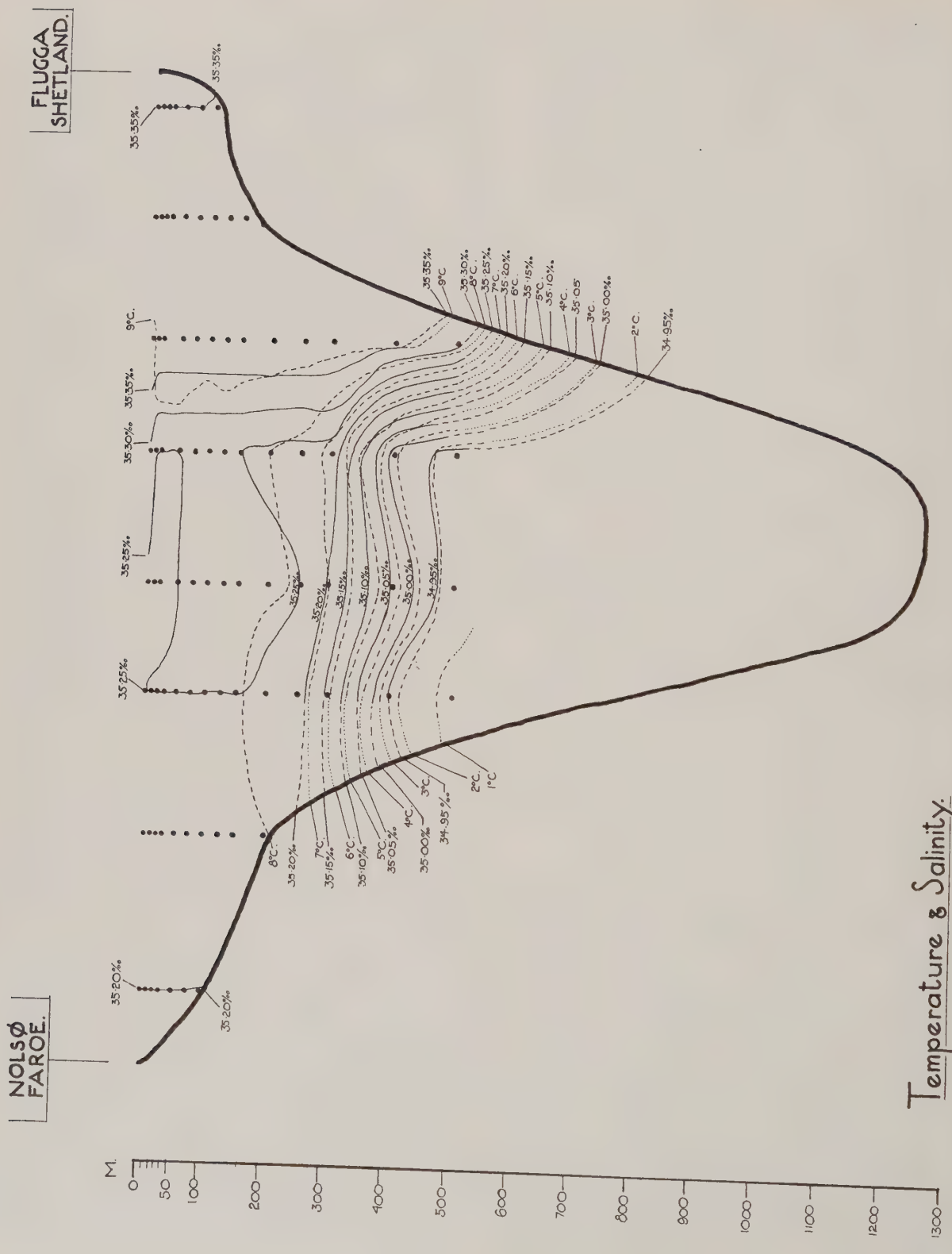


Figure 14. Nolsø, Faroe/Flugga, Shetland. M.S. "G. O. Sars". 15.—16. December 1958.

led the deeps between the Wyville Thomson Ridge
ıd Faroe Bank.

Only the former deep water type was located on
e other, the north-western side of Faroe Bank,
ıile further to the north-west only water of 3°—
°C temperature which had the salinity of weak
eanic water, was found on the bottom of the
uth-eastern slope of the Iceland-Faroe Ridge. Nor
ıes Figure 13 reveal in these bottom waters, even
those with a temperature inferior to 3°C, but above
°C, any evidence of the overspill of cold deep water
ɔm the Norwegian Sea south-westward across the
eland-Faroe Ridge. The whole of these shallower
ɔpes of the ridge near its summit appear, in Sep-
mber 1958, to have been bathed in distinctive
eanic water which apparently reached even to the
ɔttom in 1400 metres, the deepest part of this
tension to the section over against Iceland.

Figure 14 illustrates the temperature and salinity
stributions between Shetland and Faroe as observed
ɔm the Norwegian research ship "G. O. Sars" on
e 15.—16. December 1958. Here again a very high
eanic volume transport of 20 km³/hr was com-
ıted, and the core of the Atlantic Current was
ɔviously centred very nearly on the third station out
ɔm Shetland where a salinity of 35·40 ‰ was re-
rded at all levels from the surface to 300 metres
pth. The base of the oceanic water mass at
·00 ‰ salinity exhibits the characteristic shape of
ild undulation between 375 and 425 metres for
ɔ-thirds of the section from the Faroe Shelf slope,
with a steep dip to over 700 metres on the continental slope north-west of Shetland.

Unfortunately the lack of deep water observations precludes the definition of these waters as to their probable origin.

To sum up, we have, in these twelve IGY traverses of the Faroe-Shetland Channel, evidences of: —

(1) abnormally powerful impulses of the Atlantic Current at the beginning and end of the IGY,
(2) the inclusion of Gulf of Gibraltar water on the oceanic water mass pulsations of June 1957 and June 1958,
(3) the almost complete cleavage of the north-eastward trending oceanic water mass by southward moving tongues of (a) intermediate Arctic water in June 1957 and (b) bottom Norwegian Sea water in June 1958, and,
(4) in June 1957 and March 1958*), the overspill of cold deep Norwegian Sea water over the Iceland-Faroe Ridge, but no evidence of this phenomenon in November-December 1957, June and September 1958.

*) It will be recalled that further evidence was found by Steele in the beginning of August 1958 (Steele, 1959).

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11.

Notes on the Deep Water Overflow Across the Iceland–Faroe Ridge

By

J. H. Steele

Marine Laboratory, Aberdeen

Dietrich (1956) has described the conditions across the Iceland–Faroe Ridge due to the overflow of "Arctic" type water near the bottom. This note discusses the direction and speed of the cold water overflow as it moves down the western slope of the ridge into the basin south of Iceland.

In July–August 1958 the Scottish research ship "Explorer" worked a grid of stations in this area (Fig. 1) and also carried out a short investigation of an overflow of particularly cold water at the position shown by the arrow (Steele, 1959).

The main features of the water distribution down the ridge are shown in Figure 2 which is a section south-west off the shelf. The eastern part is similar to Dietrich's sections which he interpreted as a flow down the ridge of the colder, denser water. At the same time the slope of the iso-lines could imply a geostrophic motion to the north-west and it is the combination of these two effects that will be considered here. The result of this possible combination is shown by the depth distributions of σ^t values. The $\sigma_t = 27{\cdot}4$ corresponds to a temperature of 4° C and a salinity of 35·00‰ and so, roughly, can be taken as the upper boundary of the overflow. The depth of this value is charted in Figure 3, showing the same general feature of flow down the ridge. It also shows, however

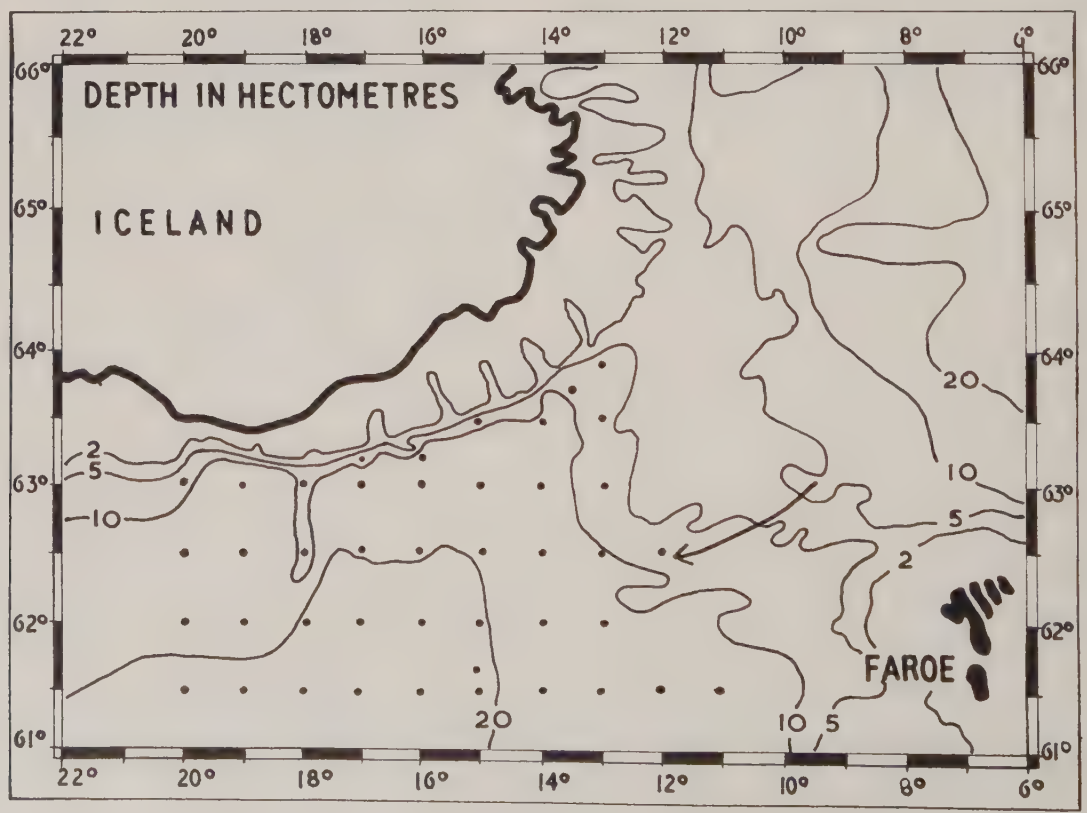

Figure 1.

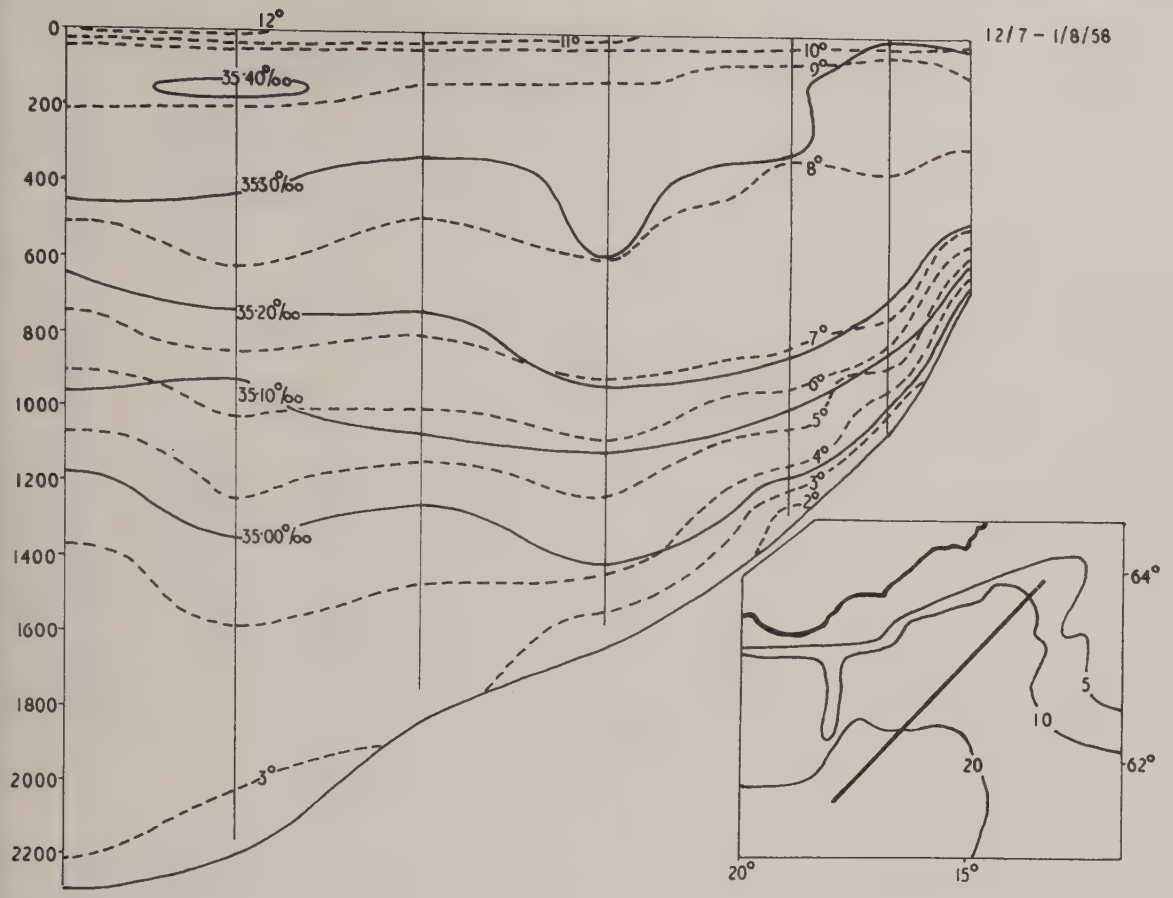

Figure 2.

lat the density surface slopes steeply along the south-ıst coast of Iceland till it is apparently "deflected" ' the ridge that runs out from the coast at about 3° W. This implies a geostrophic flow round the des of the basin.

Further this strong deep current along the south Iceland was not peculiar to this survey since it as observed on three occasions in the previous year. igure 4 shows the temperature data from a section cross this flow worked in April, June, and Sep-mber, 1957. If volume transports are calcu-ted in the usual way assuming that the surface elocity is zero, then excessively high values of 11·9 13·4 $\times 10^6$ m^3/sec. are obtained. The lower water ansport can be reduced to reasonable values of 0 to 3·0 $\times 10^6$ m^3/sec. (see below) by taking the ro level at 1000 m, but this in turn introduces very gh values of 6·3 to 8·4 $\times 10^6$ m^3/sec. for the trans-orts of the upper waters. From this it seems reason-ble to say that the flow through this section still as a downward component and so is not purely eostrophic.

A simple theoretical picture combining the geostrophic and gravitational components of flow on a slope can be constructed as follows. Consider a bottom layer of constant thickness, η, and density, ϱ_2, lying on a slope of angle, α, under water of density, ϱ_1. Let the x-axis be down the slope and the y-axis along it. Then with the usual notation, the mean motion in the layer is given by: –

$$\frac{dv_x}{dt} = -2\omega \sin \varphi v_y - \frac{1}{\varrho}\frac{\partial p}{\partial x} + g \sin \alpha + \frac{1}{\varrho} R_x$$

$$\frac{dv_y}{dt} = 2\omega \sin \varphi v_x - \frac{1}{\varrho}\frac{\partial p}{\partial y} + \frac{1}{\varrho} R_y$$

If the angle of the flow to the slope is λ then,

$$v_x = v \cos \lambda, \; v_y = v \sin \lambda.$$

Assume that the friction forces act at a boundary with coefficient of friction, μ, so that the mean force in the layer is, in the usual form,

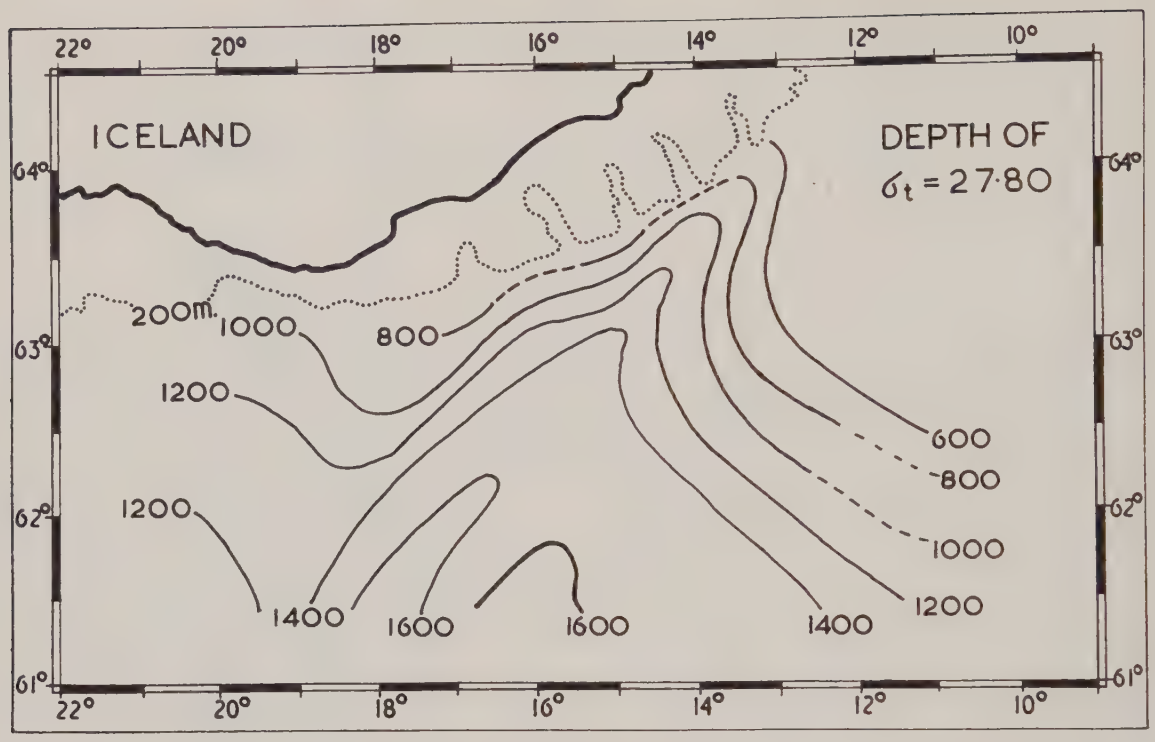

Figure 3.

$$\frac{1}{\varrho} R_x = -\frac{\mu}{\eta} v^2 \cos \lambda, \frac{1}{\varrho} R_y = -\frac{\mu}{\eta} v^2 \sin \lambda.$$

Then for steady state conditions, with $2\omega \sin \varphi = f$,

$$-fv \sin \lambda + \frac{\varrho_2 - \varrho_1}{\varrho_2} g \sin \alpha - \frac{\mu}{\eta} v^2 \cos \lambda = 0$$

$$fv \cos \lambda - \frac{\mu}{\eta} v^2 \sin \lambda = 0.$$

These give

$$v = \frac{f\eta}{\mu \tan \lambda}$$

$$\cos \lambda = \frac{\sqrt{4\beta^2 + 1} - 1}{2\beta} \text{ where } \beta = \frac{\varrho_2 - \varrho_1}{\varrho_2} \cdot \frac{\mu g \sin \alpha}{\eta f^2}$$

Some values for v and λ for a range of μ are given in Table 1, assuming that $\varrho_2 - \varrho_1 = 0{\cdot}4 \times 10^{-3} \sin \alpha = 1/150$, $\eta = 50$ m.

Table 1

μ	0	·01	·03	·05	∞
λ	90°	72°	52°	30°	0°
v cm/sec	52	20	16	11	0

From the rather rough observations made on the isolated overflow of very cold water, the value of λ appeared to lie between 45° and 60°. Thus the value of μ required to produce this is $\mu = {\cdot}03$ and the resultant velocity would be about 16 cm/sec.

The problem is to justify the use of $\mu = {\cdot}03$, since this value is about 10 times greater than that generally found for the effects of bottom friction due to tidal action in channels (Bowden, 1956). The higher value, however, is the one used by Defant (1955) in the study of two-layered flows in channels and gives good agreement with observations. Although Defant attributed the resistance to bottom friction, it might be that the turbulent shearing forces between the two layers is the main form of friction force in the two-layered case.

The flow down the ridge is obviously similar to Defant's case and so the value of $\mu = {\cdot}03$ has that much justification. In an attempt to decide if the turbulent mixing could provide a sufficient loss of energy, the vertical spread of the isotherms westward along the section in Figure 2 is taken as an indication of the effects of vertical mixing. Figure 4 shows a plot of the vertical distance between the 4° and 6° isotherms with increasing distance along the section. If it is postulated that the spread is due to

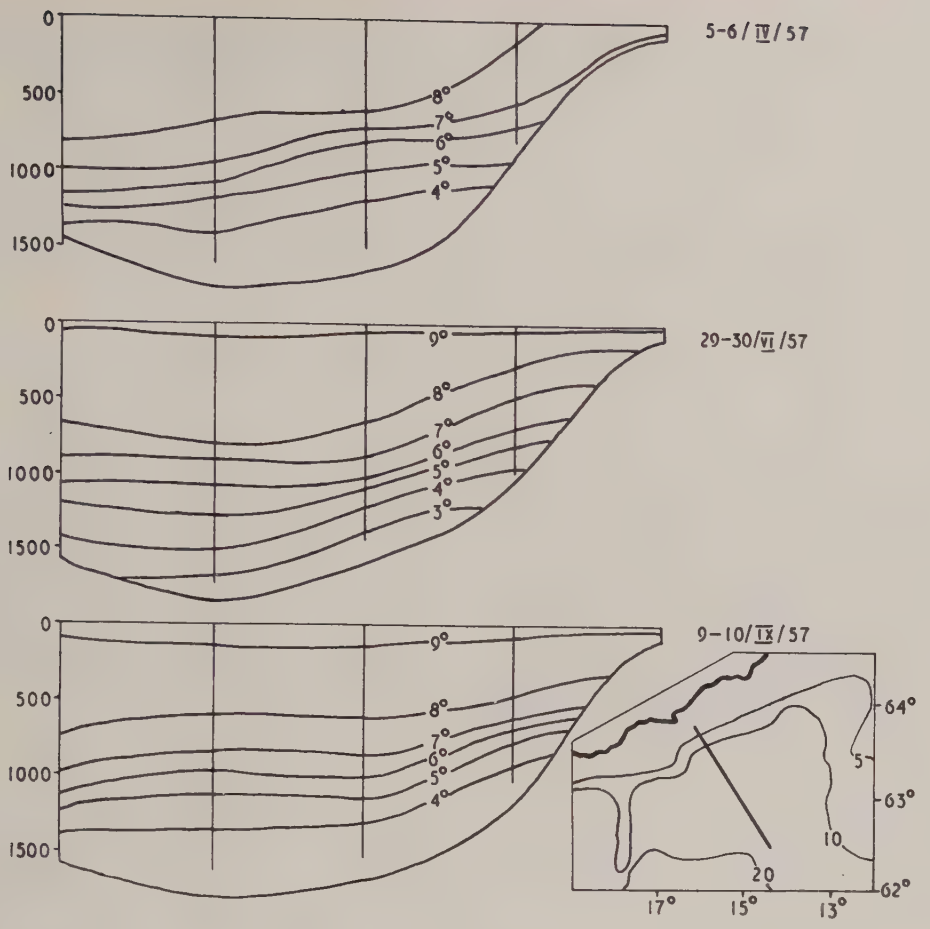

Figure 4.

ıe upward mixing of the colder water then increase potential energy relative to the lower isotherm a rough measure of the energy loss from the lower yer. Assuming that there is constant loss along the ction to produce the potential energy found at 40 km, then the rate of loss per unit distance is dynes/cm². The value of R_x for $\mu = \cdot 03$ is 5·4 dynes/m² and so it seems possible that turbulent mixing ıto the upper layer rather than bottom friction may e mainly responsible for the higher value of μ.

Discussion

The surveys carried out in 1957 and 1958 suggest ıat, although there may be variations in its magnitude, ıere is a continuous flow of cold water over the Ice-nd–Faroe Ridge. This water at a temperature of –4° C is probably the result of considerable mixing ı top of the ridge between the "Atlantic" and

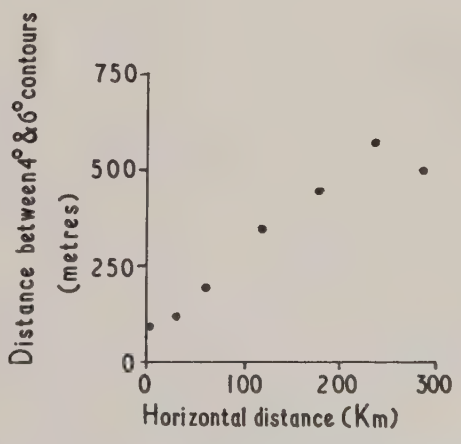

Figure 5.

"Arctic" type water masses. Overflows of colder, nearly pure "Arctic" water, 0°–2° C, are probably comparatively sporadic. The area was sampled in *June* and November, 1957; *March*, June, *August* and November, 1958; July, 1959 (Tait and Martin, this volume). Only in the months in italics was any trace of the very cold water observed. These lower temperature overflows are probably not of any great quantitative importance except perhaps to provide a source for the very lowest bottom temperatures found to the south. Their main interest is that they indicate the angle of the flow to the slope and so provide insight into the forces operating on the general overflow.

It appears that the flow is turned to the northwest and forms a strong under-current along the lower edge of the continental slope south of Iceland, similar to the flow along the edge of the continental slope east of Greenland described by Dietrich (1957). This narrow current seems to be deflected and broken up by the ridge which runs out from Iceland at about 18° W producing the broad deep current east of the Reykjanes Ridge which is to be found in Dietrich's (1957) observations and in the numerous "Dana" sections in the Annales Biologiques.

Finally, the total water transport over the ridge can be estimated roughly by taking the velocity calculated here and assuming that the thickness of the overflow varies from 50 to 100 m. The range is then 1·5 to 3·0 × 10^6 m^3/sec. (Dietrich (1956) neglected the geostrophic component and obtained rather larger transports). This is near the mean value for flow through the Faroe–Shetland Channel (Tait, 1957) and gives an indication of the possible magnitude of the overflow.

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IV. DENMARK STRAIT AND DAVIS STRAIT

12.

Meteorologically Forced Internal Waves in the Region South-West of Iceland

By

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The significance of vertical oscillations in the sea been known since the earlier work of Helland-nsen and Nansen (1909), and several authors have cribed these phenomena during the last 50 years. e present discussion is based on the short periodic nperature variations which were observed to occur various fixed levels at "Anton Dohrn" station 2293 ring a 36-hour period of observation, 8 a.m. on March to 10 p.m. on 24. March 1958. For pur-es of this investigation it was desirable to locate a ion where horizontal gradients of temperature and nity would be as small as possible for a con-erable distance in all directions. Such a condition s nearly attained by locating station 2293 at a ition in the Irminger Current ($\varphi = 61°34'$ N, 22°45′ W). The ship was not anchored and oc-ional steaming back to position was necessary. ecks on the amount and direction of the ship's ft were maintained by frequent observations with Loran navigator. All observations were made hin a one mile radius of the mean position of the ion. The depth was 1820 m.

Regarding theoretical studies (Krauss, 1959a) we ve to expect two different kinds of internal waves the ocean:—

- internal tidal waves with the period of the tide-producing forces and wave lengths varying between 20 and 100 km;
- internal inertia waves with the period of inertia and a wave length corresponding to the scale of *slowly* moving meteorological forces, for instance central depressions of the northern regions.

nternal tidal waves are well known and have been erved by several authors. The same is true re-ding to internal inertia waves. The main aim of observations at station 2293 was to study the aviour of the deep water layers in relation to the meteorological forces. The meteorological conditions during the second half of March had been very favourable for the production of internal inertia waves, as has been shown by the author (Krauss, 1956). With a period of about 9 days the wind reached maximum values on 14.–15., 23.–24., and 31. March. From theory we know that such long periodical forces must produce co-oscillating waves with the above-mentioned inertia period and a very long wave length.

At the beginning of the observations the entire water column from surface to bottom was sampled, then sampling was limited to the range 450 m to 1350 m, the region of maximal temperature gradient. The mean distribution of temperature, salinity, and σ_t is shown in Figure 1. It may be characterized by warm and haline Atlantic water down to 600 m: then follows the thermo- and halocline and the deep water. Near the bottom we find water of high salinity (35·25 ‰). The sample has been titrated twice, but seems to be very doubtful.

The mean values of temperature, salinity and density, however, are not very representative compared with the actual ones. The material has been presented elsewhere (Krauss, 1959b). In the case of temperature the fluctuations are very great.

If the observations contain the influence of meteorological forced inertia waves, we have to expect a variation of the amplitude of the waves as a consequence of the varying wind force. The wind had been 6–7 Beaufort at the beginning of our observations and had risen to 8 and 9 Beaufort at the end of the station. It seems, therefore, that the earlier data of the observation period contain the influence of the wind to a lesser degree.

Bearing this in mind, we first of all analysed the tidal influence. Harmonic analysis was carried out on data obtained during the beginning of the station.

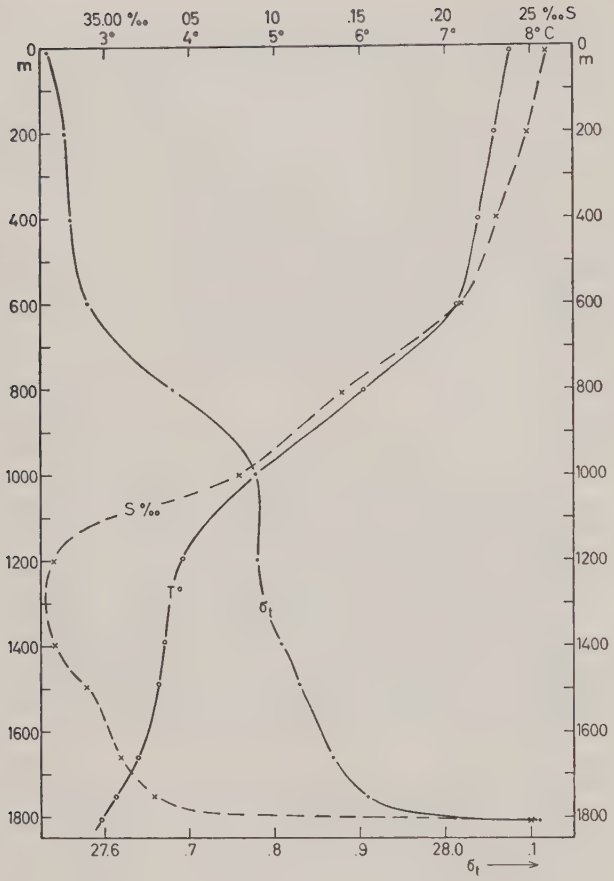

Figure 1.

The 24 lunar hour wave was most pronounced and its amplitude attained significant proportions in the thermocline layer. The semidiurnal wave was less pronounced, as may be seen from Table 1.

Table 1

(* = maximum values)

Tidal influence upon the temperature

Depth (m)	Semidiurnal wave		Diurnal wave	
	Amplitude	Phase (hours)	Amplitude	Phase (hours)
500	0·06	5·87	0·10	6·79
600	0·08	8·38*	0·13	10·57*
700	0·09	4·58	0·36	10·04
800	0·06	4·06	0·34	9·78
900	0·06	3·50	0·20	9·70
1000	0·08	2·32	0·11	9·31
1100	0·05	2·47	0·08	11·81
1200	0·06	3·42	0·06	13·53*
1300	0·07	4·00	0·03	10·39

The real amplitudes ζ of the vertical movements are given by the well known relation

$$\zeta = -\frac{T}{\frac{dT_0}{dz}} \qquad (1)$$

(T = actual temperature, T_0 = mean temperature) They are shown in Table 2.

Table 2

Real amplitude A of the vertical movements of the semidiurnal and the diurnal internal waves

Depth (m)	Semidiurnal wave (m)	Diurnal wave (m)
500	64	77
600	23	(45)
700	12	67
800	14	52
900	10	32
1000	9	20
1100	17	19
1200	28	23
1300	46	27

It is a remarkable fact that the amplitude of th most pronounced wave reaches maximal values no only at 500 m but also at 1300 m. The whole dept of the water column was nearly 1800 m. In order t test these results, we computed the theoretical di tribution of the amplitude of the internal waves b means of our electronic computer at Kiel University We found that the real distribution in the ocea consists of 3 internal modes and especially that th internal wave of the second mode with maxima values at 450 and 1350 m is responsible for the ob served extremes near 500 m and 1300 m (Table 2) The differences between the observed values and th computed ones are small. Eliminating these tidal in fluences from the data, we get residual temperatur curves for each depth. These are shown in Figure 2

The curves show great variations, but no definit periodicity arising from regular oscillations can b traced, although a few of the greatest variation coincide with the inertia period of 13·6 hours. Fron a theoretical point of view even that must be ex pected.

Meteorologically forced internal waves are a type c co-oscillating waves, as has been shown by the autho They are governed by the equation

$$\frac{d^2w}{dz^2} + \frac{\varkappa_m^2 g}{\omega^2 f^2} \cdot \frac{S'}{S} w = 0 \qquad (2)$$

with $\varkappa_m = \frac{2\pi}{\lambda_m}$. The wave length λ_m is given by th scale of the meteorological forces.

If $\nu_n^2 (n = 1, 2, 3, \ldots\ldots)$ represents the Eigen values of the equation, there follows

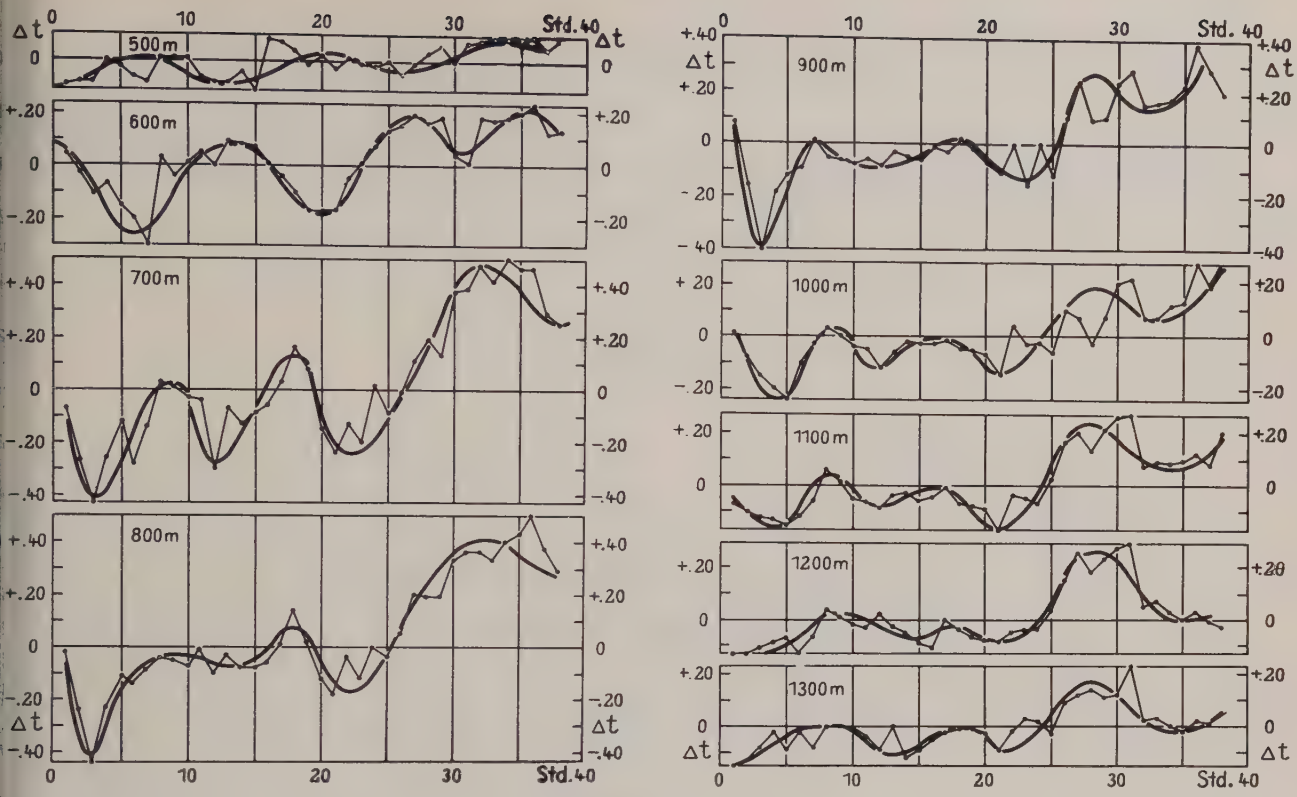

Figure 2.

(3) $$T_n = \frac{2\pi\lambda_n}{\sqrt{(f\lambda_n\nu_n)^2 + 4\pi^2 g}}$$

According as the wave length of the excitant force, and as the order of the internal waves increase $(f\lambda\nu_n)^2 \gg 4\pi^2 g$, the forced oscillation adopts the period of inertness, $2\pi/f$.

Meteorologically produced internal waves are therefore remarkable for their interferences. The period consists of a sum of partial waves according to the above equation,

$$T = \sum_n T_n \; (n = 1, 2, 3, \ldots).$$

Examples with numerical values reveal that even meteorological power fields covering $\lambda_0 = 2000$ km still do not yield the inertial period for the internal waves if $n = 1$.

As for the internal waves of second order, ν_n being approximately equal to $n\nu_1$, the influence of the second member of equation (3) strongly decreases according to $\nu_n^2 = n^2\nu_1^2$, so that the higher oscillations practically adopt the period of inertness in any case. Apart from the period of inertness one will always find at least one oscillation with a slightly smaller period. The interference of these two waves

$$\eta_1 = a_1 \cos(\omega_1 t - \varepsilon_1)$$

and

$$\eta_2 = a_2 \cos(\omega_2 t - \varepsilon_2)$$

leads by means of

$$\alpha = (\omega_1 - \omega_2)\, t - \varepsilon_1 + \varepsilon_2 \text{ and } \beta = arc\ tg\ \frac{a_2 \sin\alpha}{a_1 + a_2\cos\alpha}$$

to an oscillation of the form

$$\eta = A \cos(\omega_1 t - \beta - \varepsilon_1),$$

in which the amplitude fluctuates between $a_1 + a_2$ and $a_1 - a_2$

$$A = \sqrt{a_1^2 + 2\, a_1\, a_2 \cos[(\omega_1 - \omega_2)\, t - \varepsilon_1 + \varepsilon_2] + a_2^2}$$

and in which the period and the phase are determined by the expression

$$\cos\left\{\omega_1 t - arc\ tg\ \frac{a_2 \sin[(\omega_1 - \omega_2)\, t - \varepsilon_1 + \varepsilon_2]}{a_1 + a_2\cos[(\omega_1 - \omega_2)\, t - \varepsilon_1 + \varepsilon_2]} - \varepsilon_1\right\}$$

The period thus varies between two values, one of which lies near the mean value of the two waves, whereas the other value is about half that of the smaller wave.

Figure 2 is in good agreement with these results. As can easily be seen, the period always varies between two distinct values: 13·6 and about 7 hours.

This means that the wind influences not only the upper layers of the ocean but that the deeper strata respond very remarkably to the external forces.

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13.

Canadian Contribution to IGY Polar Front Survey North Atlantic, 1957—1958

By

W. B. Bailey

Fisheries Research Board of Canada, At antic Oceanographic Group

The Canadian contribution to the IGY Polar Front survey of the North Atlantic in 1957/58 consists of data collected along three sections running outwards across the southern portion of the Labrador Shelf, the Grand Banks, and the Scotian Shelf. These data were collected by personnel of the Fisheries Research Board of Canada stationed at the Biological Station, St. John's, Newfoundland, and at the Atlantic Oceanographic Group, St. Andrews, N. B.

The northernmost section comprising eight stations running north-eastward across the southern portion of the Labrador Shelf was occupied on two occasions, in August 1957 and in August 1958. The central section running eastward from Newfoundlan across the northern portion of the Grand Banks i the latitude of the Flemish Cap included eleve stations and was occupied on four occasions, namel July 1957, March, July, and October 1958. Th southernmost section running south-eastward acro the central part of the Scotian Shelf was occupie five times, namely: late June 1957, April, Ma August, and October 1958.

The data collected included surface and subsurfac observations of temperature and salinity, depth, me teorological observations, sea state, and bathythermo grams.

14.

Hydrochemical Observations in the Davis Strait in Spring 1958

By

M. V. Fedosov and V. Andreev

VNIRO, Moscow

During May/June 1958 some hydrochemical observations were carried out in Davis Strait on board the trawler "Novorossiisk". Three sections were run that allowed data to be obtained on the intensity of photosynthesis and the rate of disintegration of organic matter in these waters.

Observations were carried out on sections running from the west coast of Greenland across the strait towards its middle (see Figure 1). The first section was run from the area of Frederikshaab and Anoritok Island towards Nachvak Bay, Labrador. The second section was run from a point 15 miles south of Ameralik Fjord towards Cape Chidley, and the third one from a point 10 miles south of Niakungunak Fjord towards Leopold Island near Cumberland.

Observations were made on the thermo-haline conditions in the water column and on the concentration and biochemical demand of oxygen, as well as on the phosphate and nitrite regime in these waters.

During the period of observation the upper water layer was taken up by cold water on almost every station. Water with temperatures below 1°C, and in some places below 0°C, extended from the surface to a depth of 100—110 m in the southern and to 170—200 m in the northern part of the area. Waters in this surface layer were 3 to 4 % diluted as against subsurface waters and had salinities between 33·45 ‰ and 33·85 ‰.

The warmest waters situated under the cold waters cover the whole bed in the area.

The 3°C isotherm in the southern part of the area investigated ran at a depth of about 200 m, and in the north-eastern part at a depth of about 300 m.

Against this hydrological background the oxygenation of the upper layer at times reached 119—125 %, in most cases resulting from the activity of phytoplankton.

Even at 100 m the water was slightly oxygenated, which is also possible with the cooling of warmer waters. However, starting from the 150 m layer, the oxygenation tends to increase towards the surface and reaches for the whole 0—50 m thickness 10 to 14 % on an average.

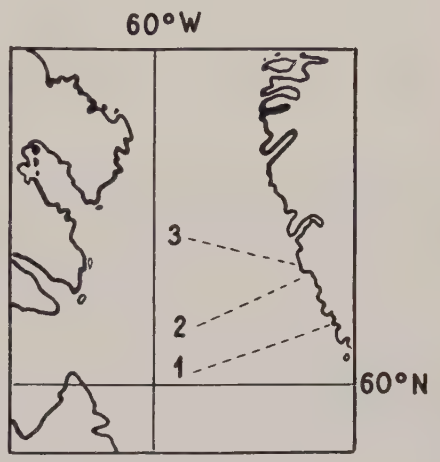

Figure 1. Chart of sections.

Calculations of the intensity of photosynthesis from the difference between the oxygen content in the 0—25 m layer prior to the morning hours (night minimum) and that in the afternoon hours (day maximum) give for all three areas of observation average increment values from 0·30 to 0·34 ml of O_2 for 24 hours (0·027—0·030 μg-at. O_2/litre).

Special observations on water samples which had been taken from various layers and which had been incubated in bottles at a temperature close to that of the surface layer (0°C—1°C), have allowed us to determine the intensity of biochemical oxygen demand in these layers. The intensity of biochemical consumption of oxygen in the upper water layer (0—50 m) equalled 0·90—1·10 ml O_2/litre (0·08—0·10 μg-at. O_2/l) for a period of ten days. The value of the coefficient of biochemical oxygen demand

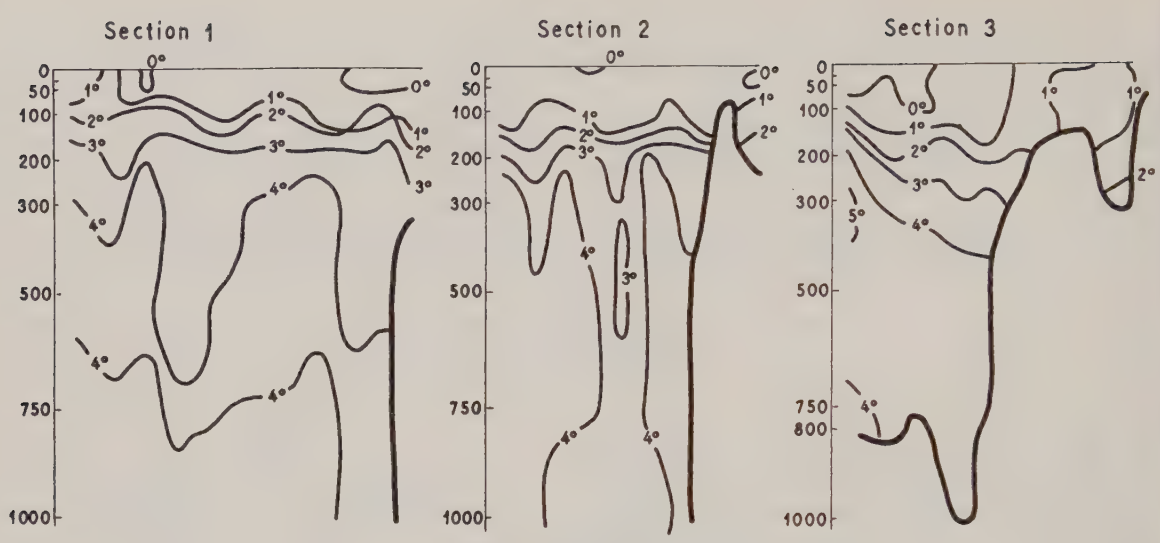

Figure 2. Isotherms.

(K_{BOD}), characterizing the nature and biochemical state of organic matter subjected to biochemical oxidation, was in all cases 0·1—0·2 on an average. It is known that in such cases not less than 25 % of the total quantity of mineralizing organic matter is oxygenated within the first 24 hours. The corresponding average values for the above investigations are 0·23 ml of O_2/l for 24 hours (0·02 μg-at. O_2/l).

Hence, it can be concluded that the "pure production", or absolute increment of organic matter of phytoplankton, in the area for the period of investigations would equal 0·07—0·11 ml O_2/l for 24 hours (0·006—0.01 μg-at. O_2/l). Converting it for glucose, we get 0·09—0·15 ml as the increment of primary organic matter for 24 hours.

Observations on the biochemical oxygen demand of certain horizons were conducted by means of water samples poured with all necessary precautions into sterilized bottles supplied with ground-in stoppers. Tightly closed bottles, placed in a water tank, were put into a hold and kept there in complete darkness and under constant temperature.

After the incubation was completed the bottles were taken out of the tank and their water samples mixed with reagents. After solidification the precipitates were dissolved in hydrochloric acid. The difference between the oxygen content before and after the incubation corresponded to the consumption of oxygen for a given time.

The value of the coefficient of biochemical oxygen demand was calculated by means of the formula:

$$K = \frac{1}{t} \log \frac{BOD_t}{BOD_{2t} - BOD_t}$$

where

t = number of days of incubation during th first term.

$2t$ = double number of days of incubation duri the first term.

Skopintsev has shown that the complete minera ization of organic matter does not come after 2 days of oxygenating processes (at 20°C), and som of it still remains in the form of stable compounds water humus. The mineralization of the latter pr ceeds more slowly and the coefficient, K, is in th case less than 0·1.

At the same time the value of the biochemic oxygen demand in sea water is known to grow wit the increase of organic matter of the same qualitati composition.

The results of all these observations in Dav Strait gave the average values of relative intensit of biochemical oxygen demand for different se water layers listed in Table 1.

Table 1
Intensity af biochemical oxygen demand in different water layers

Layer	Average diurnal *BOD* (ml O_2/litre) (with incubated samples)		
	10 days	20 days	40 days
0 m	$0{\cdot}11_0$	$0{\cdot}11_3$	$0{\cdot}06_3$
50 m	$0{\cdot}09_0$	$0{\cdot}06_7$	$0{\cdot}05_6$
500 m	0·01	$0{\cdot}01_2$	$0{\cdot}01_5$

Comparing these data one may infer that th organic matter of surface water becomes withi

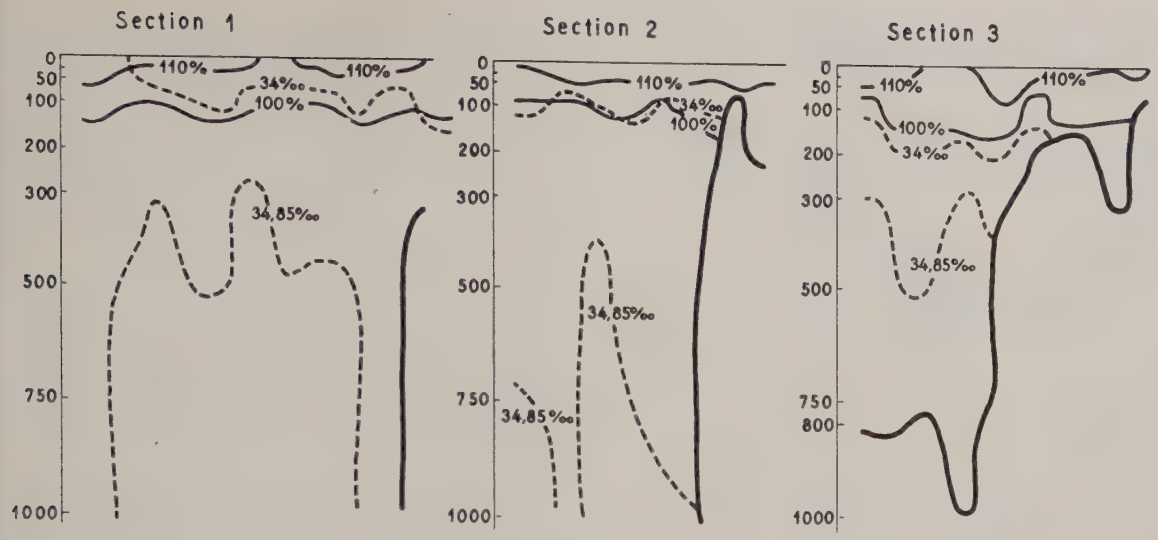

Figure 3. Isoxygens and isohalines.

50 days equivalent to that in the 50 m layer. However, as regards the intensity of oxygen consumption, the waters of the 500 m horizon greatly differ from the waters of the upper photic layer. The low intensity of *BOD* in deep water masses may be used as an indicator of these waters.

The decomposition and mineralization of the organic matter of dying plankton was proved by the considerable amount of nitrite (0·6—1·5 μg/l) found in the water during the period of observations. In the southern part of the area nitrite was observed from the surface to 100 and 200 m. In the central part of the area nitrite was not found in the surface layer to 25 m depth, and in the northern part there were but traces of nitrite or it was absent altogether to the depth of 50 m.

On the other hand, relatively small quantities of phosphate in the upper 25 m layer, as compared with the concentration of phosphates in the subsurface 50—200 m layer, indicate that the phytoplankton in the course of life rather actively assimilated nutritious salts of phosphorus.

Table 2

Minimum and maximum oxygen content in the waters of Davis Strait May/June 1958

Layer (m)	Night (early morning) minimum (0145–1150 hr)			Afternoon (day) maximum (1225–2425 hr)				
	ml O_2/litre							
0	9·29	8·56	8·59	8·97	8·90	9·21	9·08	9·49
	8·88	8·78	8·98	9·03	9·15	9·23	–	–
0	9·20	8·84	8·97	9·54	9·15	9·14	9·33	9·05
	9·63	9·96	8·80	8·96	9·49	9·15	9·29	10·03
	9·00	9·11	–	–	10·41	10·42	9·32	–
5	8·82	8·37	8·53	8·83	9·00	9·19	8·81	8·81
	8·36	9·12	8·72	8·77	8·71	9·20	8·94	9·74
	8·91	8·92	9·06	–	9·54	9·52	9·26	–
	in μg-at. O_2/litre							
0	0·825	0·7645	0·767	0·798	0·795	0·848	0·822	0·817
	0·793	0·784	0·802	0·8065	0·811	0·824	–	–
0	0·822	0·860	0·8895	0·814	0·817	0·808	0·830	0·816
	0·852	0·800	0·804	0·786	0·848	0·896	0·833	0·817
	0·7895	0·801	–	–	0·931	0·932	0·832	–
5	0·788	0·7475	0·762	0·789	0·804	0·787	0·798	0·850
	0·747	0·8145	0·779	0·809	0·821	0·778	0·870	0·827
	0·783	0·796	0·797	–	0·787	0·822	0·852	–

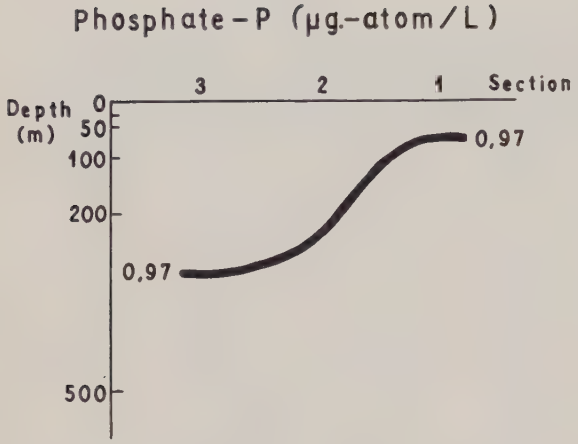

Figure 4. Phosphates.

The average content of phosphates in these wat was as follows (in μg P/1 and μg-at. P/1):—

Depth (m)	Northern section		Central section		Southern secti	
	μg P/1	μg-at. P/1	μg P/1	μg-at. P/1	μg P/1	μg-at. P
0–25....	7·0	0·23	8·2	0·27	13·8	0·45
50....	11	0·36	12	0·39	28	0·90
100....	29	0·94	22	0·71	32	1·03
200....	29	0·94	30	0·97	36	1·16
500....	33	1·07	37	1·19	37	1·19

The largest gradient of phosphate concentratio between the 0—25 m layer and the 100 m su surface layer, was observed in the northern a southern parts of the investigated area of the stra and was equal to 2·9 and 9·5 μg P/litre/10 m respe tively.

It must be admitted that the values obtain indicate primary productivity of a very high order.

V. THE NORTH ATLANTIC OCEAN

15.

A Note on the IGY Cruise Data in the Atlantic Ocean*)

By

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It would appear that the greater part of the oceanographic work undertaken in the Atlantic Ocean during the IGY has been organized under two main programmes. The ICES programme is concerned essentially with the study of the Polar Front region in the north-eastern North Atlantic, while the other programme, for which the Woods Hole Oceanographic Institution is chiefly responsible, has consisted of a general survey of the Atlantic, arranged on similar lines to the "Meteor" survey of the South Atlantic, that is to say, in east-west sections. In some cases, the "Meteor" sections have been repeated. In addition, local programmes have resulted in a number of other cruises being undertaken, some of which have been repeated on several occasions. The data from these cruises, together with the observations at the Ocean Weather Stations and at certain fixed stations operated in connexion with the mean sea-level programme, should be of great value in providing information on any major changes in conditions which may have occurred during the course of the IGY.

Figure 1 shows the stations in the Atlantic at which serial observations have been made and for which the data have been received in the IGY Data Centres, excluding some of the stations in the north-eastern North Atlantic on the ridge separating the Atlantic proper from the Norwegian Sea. These stations, which are rather crowded, are associated mainly with the Council's Polar Front survey, with the details of which, of course, the reader is already acquainted. The purpose of the present paper is to draw attention to the data available from other programmes, which may perhaps be found useful in elucidating the problems of the Polar Front and of the flow of bottom water from the Norwegian Sea into the main Atlantic basin.

The principal feature of the station chart, as may be seen, is the series of east-west sections starting in about 50°N latitude and reaching to 15°S. These are the work of the "Crawford" and "Atlantis" from Woods Hole, the "Aventure" from France, and the "Discovery II" from Britain. It is understood that the "Crawford" has run sections as far as 32°S, but these data are not yet in the hands of the WDCs. The Argentinian vessel "Capitan Cánepa" has run two sections in about 40° and 50°S latitude.

Another feature is the extensive cruise of the "Lomonosov" in the North Atlantic, which is connected with a network of sections running more or less south-east to north-west extending into the Norwegian Sea, and tying in with the Council's Polar Front survey.

Data are available for what may be termed the marginal regions on both sides of the Atlantic. On the American side, the Canadian ships "Sackville" and "Investigator II" and the French ship "Aventure" have worked in the Labrador Sea region, some of the sections being repeated up to five times. The "Atlantis" and "Hidalgo" (Woods Hole and Texas A. & M.) have worked in the Gulf of Mexico and Sargasso Sea areas, and it is understood that the "Crawford" has also worked in the Caribbean area; these last data, however, have not yet been received. The "Panulirus" has made repeated observations at a station off Bermuda; the series of observations is believed to have been started some years before IGY.

*) Contribution from the Department of Oceanography and Meteorology of the Agricultural and Mechanical College of Texas.

**) Now at the Marine Laboratory, University of Miami, Florida.

Figure 1.

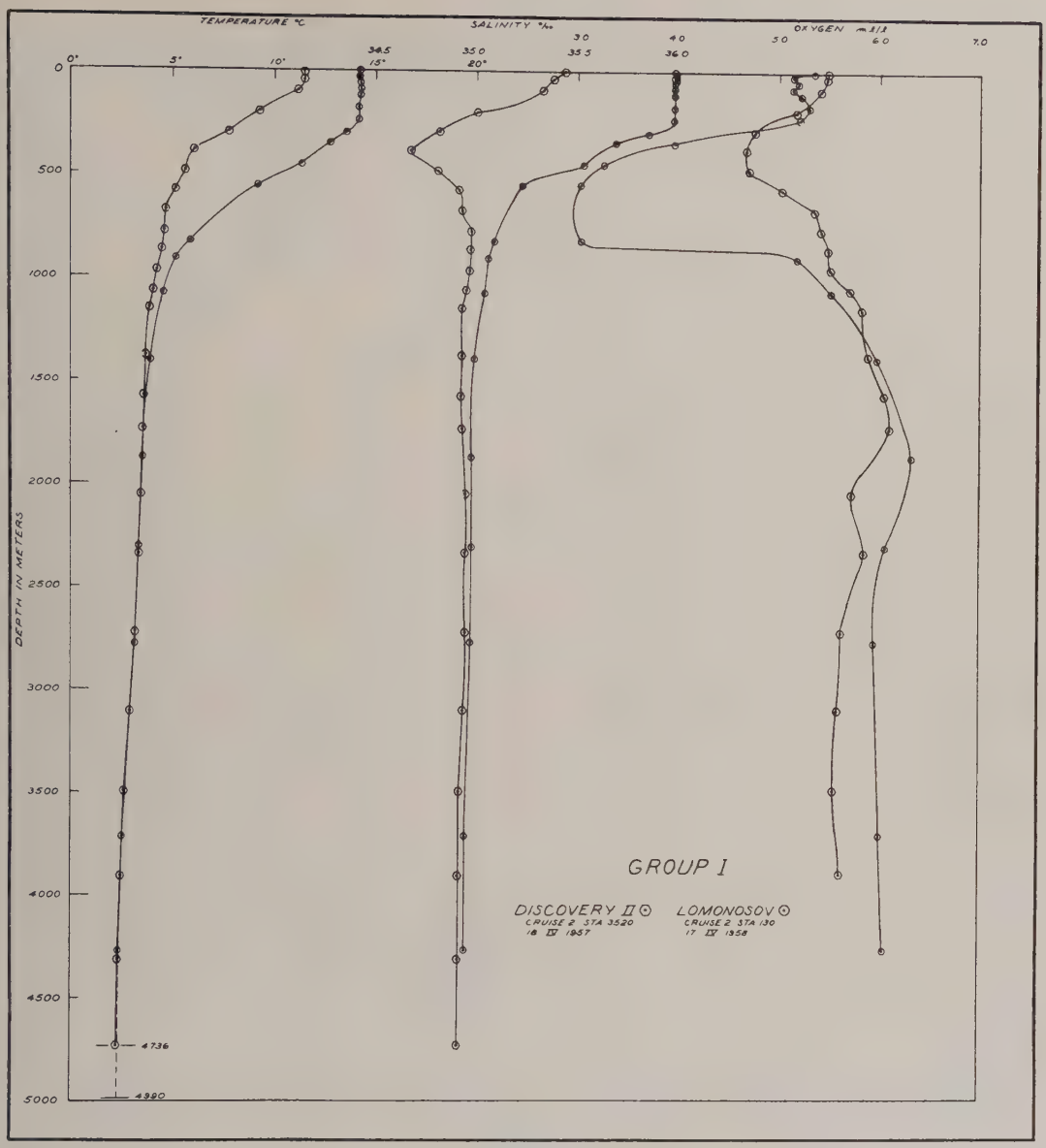

Figure 2.

The "Almirante Saldanha" (Brazil) has worked several series of sections in the Amazon region and off the south-eastern coast of Brazil. Repeated stations have been worked by Argentinian vessels off La Plata mouth, and one of these, the "Capitan Cánepa", has occupied a network of stations between Antarctica and the southern tip of South America.

On the eastern side of the Atlantic, the "Africana II" has made several repetitions of a network of stations off the south-west coast of Africa, and the French ship "Pyrrhus" has covered a close series of stations off the Guinea coast. The "Vidal" (Britain) and the French vessels "Emporté" and "Ingénieur Elie Monnier" have made a number of stations in and around Gibraltar Straits. It is believed that Spain has also carried out numerous cruises in this locality but the data have not yet been received.

It is evident that the coverage of the Atlantic during the IGY has been much more complete than has ever been achieved hitherto in such a relatively short time. When all the IGY data have been assembled, a truly monumental collection of material will be available for study. The details of the cruises mentioned here are given in the latest WDC cata-

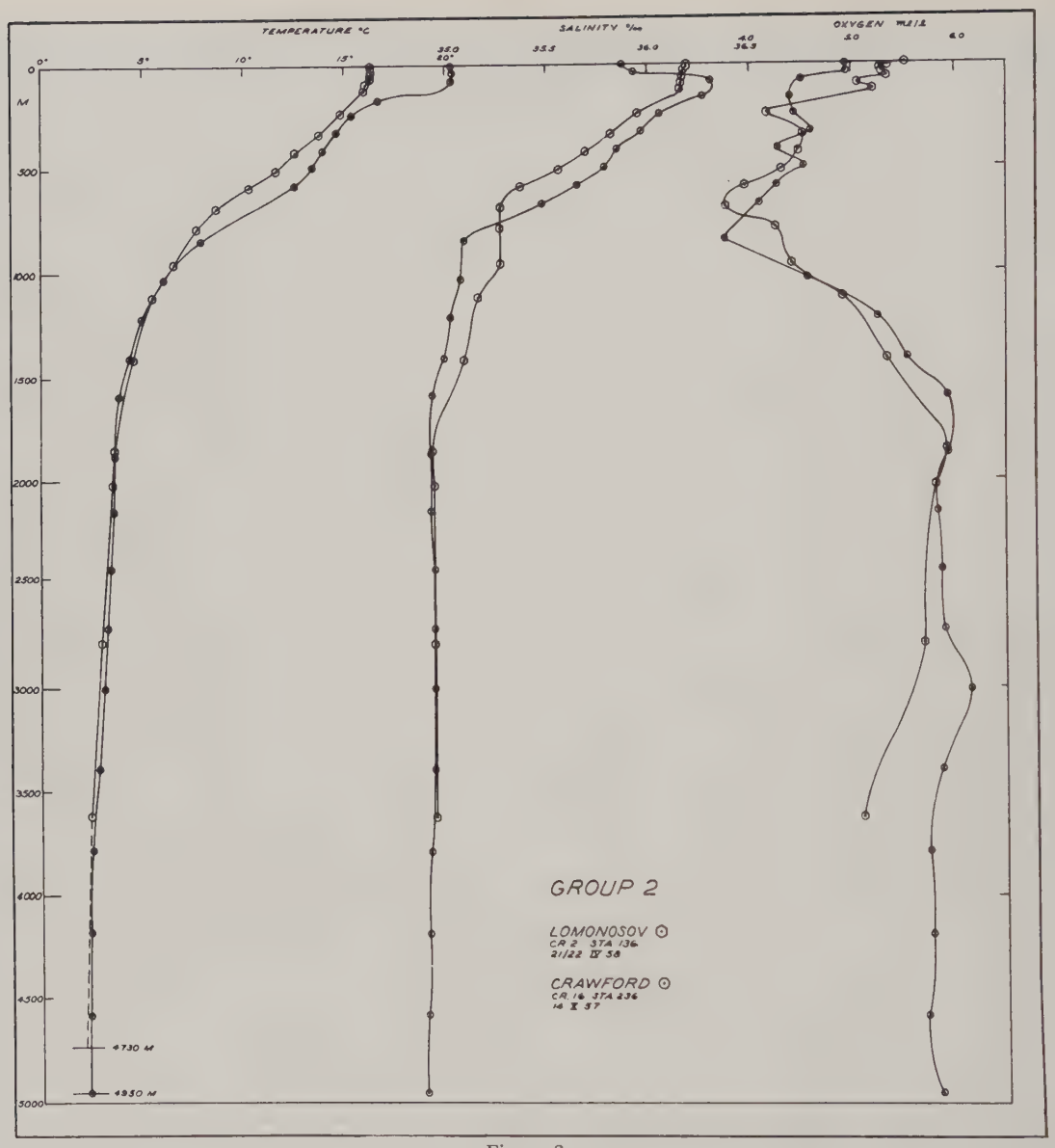

Figure 3.

logue dated 1. July 1959. Eventually, when all the IGY data have been assembled, a final catalogue will be published.

The fact that the main "Lomonosov" sections cut across those of other ships in the North Atlantic has provided an excellent opportunity for comparing observations made at different dates at very nearly the same position, and so obtaining a time series. Three such groups of stations are indicated on the chart by the large numerals. Groups 1 and 2 are in the western basin of the Atlantic, Group 3 in the eastern. In the last group, comparison can be made between the observations of 3 ships, "Av ture", "Discovery II", and "Lomonosov".

In Group 1, just south of Flemish Cap in ab 45°N, 40°W, "Discovery" station 3520, made 18. April 1957, is comparable with "Lomonos station 130, made on 17. April 1958, just a y later.

In Group 2, some 330 miles SSE of Group in about 40°N, 43°W, "Crawford" station 236, m on 14. October 1957, is comparable with "Lomo sov" station 136, made on 21.—22. April 19 that is, just half a year later.

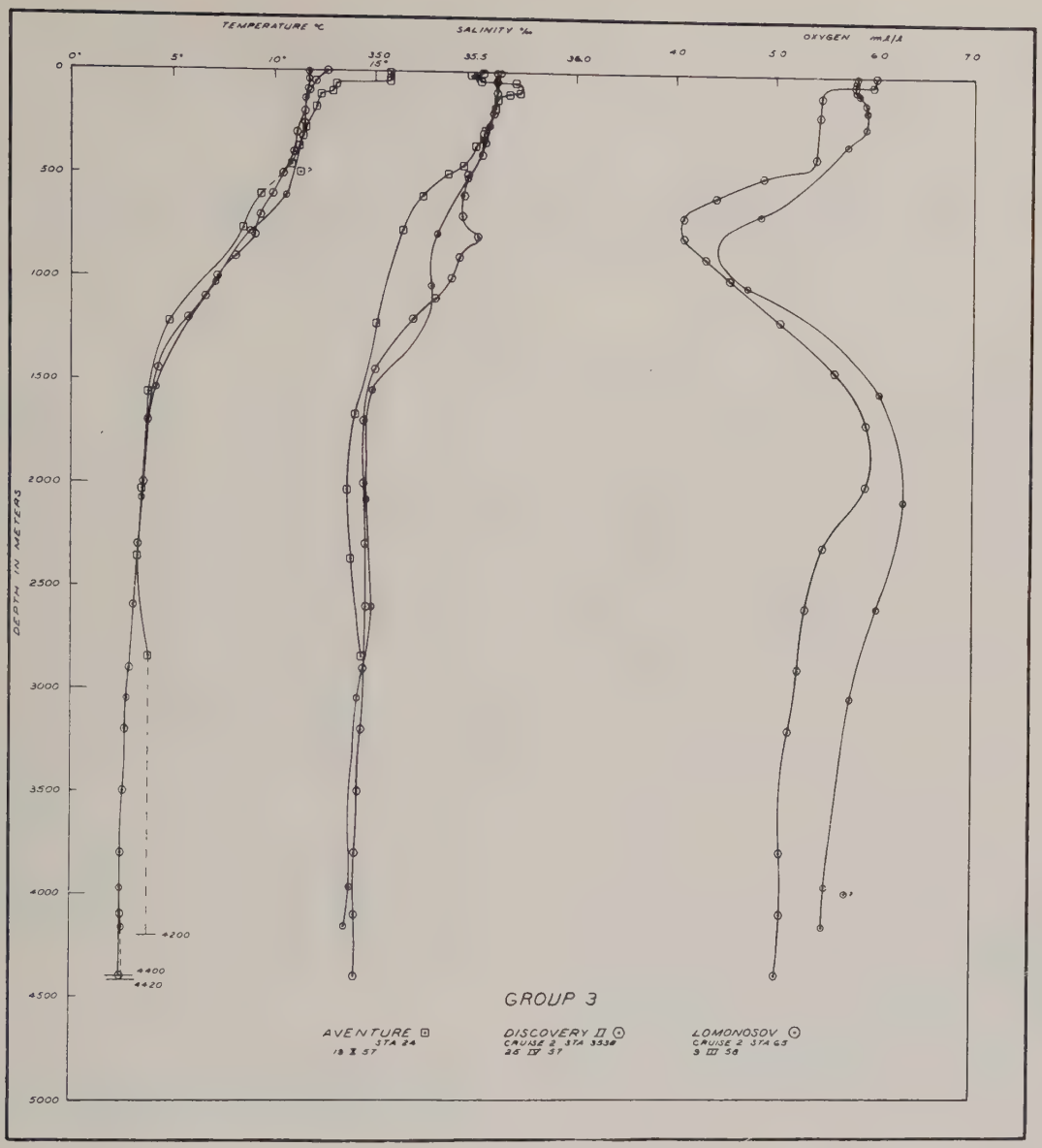

Figure 4.

In Group 3, approximately 550 miles due west of Ushant in about 48°N, 18°W, "Discovery" station 3538, on 25. April 1957, is comparable with "Aventure" station 24, on 19. October 1957, and "Lomonosov" station 65, on 9. March 1958.

The temperature, salinity, and oxygen data have been plotted for the three groups of stations, and are shown in Figures 2, 3, and 4.

The first point we may notice is that the water columns in all three localities are stable down to about 1500 m and thereafter are in neutral equilibrium. Considering only the deeper levels, we may see that very little change, if any, has occurred in temperature and salinity during the intervening periods. Perhaps the deepest temperature observed by the "Aventure" (2,850 m) is a little high, but otherwise agreement seems to be as complete as can be expected. This is not the case with the oxygen observations, however, where in the deeper levels differences occur of as much as 0·8 ml/litre.

The positions of Groups 1 and 2 are not far from one another, and all 4 stations concerned are in depths of the order of 4,500 m. The oxygen contents at 3,500 m (the deepest level for which

observations from all four stations are available) are as follows:—

Group 1 "Discovery" (Apr. 1957) 5·54 ml/litre, "Lomonosov" (Apr. 1958) 5·97 ml/litre[1].

Group 2 "Crawford" (Oct. 1957) 5·80 ml/litre[1], "Lomonosov" (Apr. 1958) 5·16 ml/litre[1].

In the eastern basin (Group 3), the interpolated values of the oxygen content at 3,500 m are as follows:—

"Discovery" (Apr. 1957) 5·09 ml/litre.
"Lomonosov" (Mar. 1958) 5·60 ml/litre.

There is also another pair of stations further south on the eastern side of the central ridge, in about 25°N, 42°W, at the intersection of the tracks of the "Crawford" and "Discovery II". This position lies just to the eastward of the summit of the ridge, however, and the conditions there may not be quite representative of those in the eastern basin proper. Moreover, both stations were occupied in the same year, in February and October, respectively, without an intervening winter, and the lower parts of the water column on the two occasions exhibit very little difference, as the following table shows:—

"Crawford" Stat. 77, 10. Febr. 1957				"Discovery" Stat. 3605, 14. Oct. 1957			
m	t° C	S ‰	O_2	m	t° C	S ‰	O_2
2595....	2·94	34·96	5·47	2591....	3·00	34·96	5·27
3395....	2·52	34·92	5·22	3488....	2·54	34·91	5·26

To attempt an assessment of the significance of the differences described is beyond the scope of the present paper. To do this, a much more searching examination is needed than it has been possible to carry out so far. Indeed, such a task would probably be better undertaken when all the data have become available. However, the differences found are so considerable that it seems worth while to dra attention to them at the present time.

In the first place the value of 5·54 ml/litre "Discovery" station 3520 (Group 1) seems to rather lower than might be expected from Dr. Wo thington's chart (1954 — Figure 3) of oxygen dist bution at 2,500 m, whereas the "Lomonosov's" val of 5·90 is in keeping with it. The "Crawford's" val of 5·80 ml/litre in Group 2 is much more consiste with this distribution, but, on the other hand, it hard to account for the "Lomonosov's" value of 5· six months later at the same position, when we reca Dr. Worthington's (loc. cit.) estimate of the annu rate of decrease in oxygen content — namely, 0·0 ml/litre — which occurs in the absence of large-sca renewal of the deeper water masses.

Such renewals may be expected to occur specially severe winters, with exceptionally low a temperatures prevailing in high latitudes. The wint of 1957/58 does not appear to have been partic larly cold — indeed, rather the reverse — bu precise figures are not available at the moment writing. Nevertheless, the Group 3 figures strong suggest that in the winter of 1957/58 a notab renewal of water took place in the deeper waters the eastern basin of the North Atlantic, as indicate by the increase in content of dissolved oxygen more than 0·5 ml/litre. Dr. Stommel's chart (1958 indicates that the expected values at 4,000 m i this locality are between 4·5 and 5·0 ml/litre, an both the "Discovery" and "Lomonosov" values ar above the upper limit of this range. However, more thorough investigation of the IGY data necessary before these apparent discrepancies ca be satisfactorily understood.

[1]) Interpolated values.

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16.

Some Thoughts on the Working-up of the Observations made during the "Polar Front Survey" in the IGY 1958*)

By

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Some steps in the Polar Front Survey, which has occupied us these few years, lie behind.

1. In the beginning there was the idea. The suggestion of the AIOP (Association Internationale l'Océanographie Physique) in Rome in September 1954 was warmly recommended by the late President of the ICES, Prof. H. U. Sverdrup at the meeting in Paris in 1954.

2. As the second step the mere idea grew to be a complex of scientific problems. As far as oceanography in my own country was concerned, I could report on it at the ICES meeting in Bergen in 1957 (Dietrich, 1957). Bückmann (1958) and Krey (1958) published contributions on problems of marine biology and organic productivity.

3. Parallel with the second step went the third, namely the coordination of the research plans of the different countries. Böhnecke (1957), the Chairman of the IGY Sub-Committee of the Hydrographical Committee was in charge of it.

4. What had been planned beforehand and been prepared in preliminary investigations was realized in 1958 in the fourth step by means of 46 research ships from 11 nations. As regards my own country, we could carry out our plans within the framework of the general programme with two ships. The routes followed and the stations of our vessels "Anton Dohrn" and "Gauss" late in the winter of 1958 may be gathered from Figure 1. Late in the summer of 1958 the cruises were repeated, with slight deviations, according to the general plan. Details about these cruises and the station lists have been published by Bückmann, Dietrich, and Joseph (1959).

5. The fourth step was followed by the fifth, the working up of the observations made. The hydrographic observations of our 558 stations were transferred to punched cards and were sent to the Service Hydrographique of the ICES and the IGY data centres A and B.

6. After these five steps, which often had only little to do with pure science but were nevertheless indispensable, we were looking forward to the sixth step, to deduce the first scientific results from our own material. What has been achieved in this respect in Germany up to now can be learnt from the "Ergänzungsheft Nr. 3, Reihe B" of the *Deutsche Hydrographische Zeitschrift* published in August 1959. The 18 contributions were made by the scientists who had participated in the IGY cruises on board "Anton Dohrn" and "Gauss". Apart from the reports of the cruises and the weather conditions, the volume contains contributions for solving physical, chemical, and marine biological problems. Points in the arrangement of the contributions are the general aim, the outline of the methods used, the explanations of the observations made and the presentations of specific results. Many other questions may be raised, I will try to do this as I proceed. Doing that, however, I want to mention the fragmentary character of some of our results. This incompleteness can only be overcome by the seventh and last step.

7. This seventh step, the exploitation of all observations made by approximately 46 research ships in the international Polar Front Survey 1958, is still to be taken. The Polar Front Survey has still to become the Polar Front Science. It is not enough to fill up the archives of the data centres with punched cards. The least thing to be done should be the compilation of an atlas containing the most important oceanographic factors in maps and selected sections of the northern North Atlantic of use as the basis of a monography. I wish to recall that the ICES has already once supported a similarly comprehensive survey, in which Martin Knudsen (1909) worked up in an exemplary way the synoptic sections made by the research ships of the member states of the ICES in the North Sea and the Baltic during the four seasons through seven years between 1902 and 1908. His work is fundamental even today. Should not the ICES carry on this tradition? It will be one

*) Dedicated to Prof. Dr. A. Bückmann for his 60th birthday.

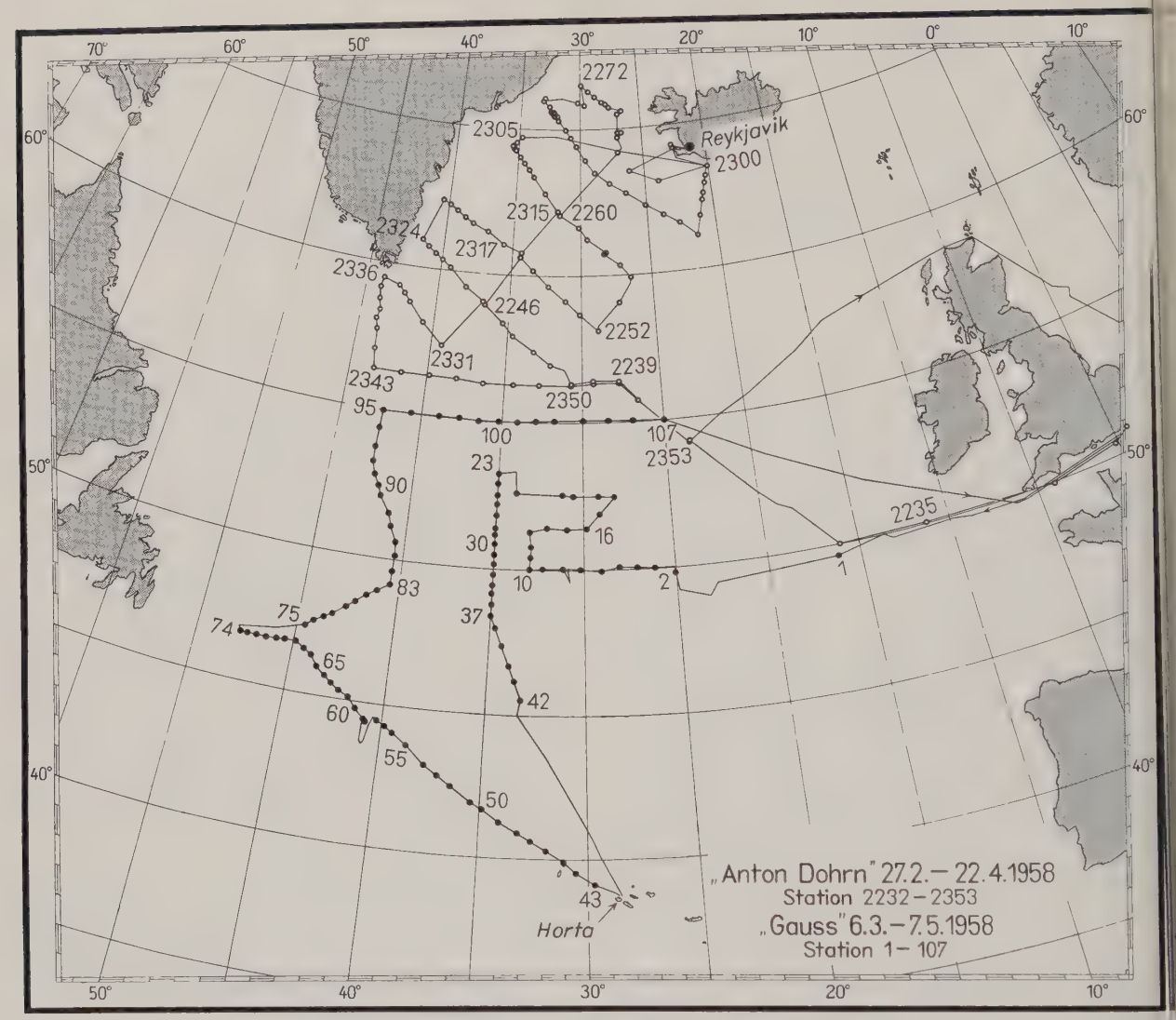

Figure 1. Routes and stations of the "Anton Dohrn" and the "Gauss" cruises in the IGY late in winter 1958.

of the tasks of *this special meeting* to arrive at a clear conception of the exploitation of the whole material.

After this survey of our seven-step ladder let us go back to the sixth step, contributions made to solve specific problems. The water masses of different origin are most easily recognized in winter, especially on a section from Cape Farewell to the Flemish Cap. For this reason we have given preference to the investigation of this section as is shown in the contributions of Koopmann (1959); Beck, Kalle, & Rogalla (1959); Krey, Hantschmann, & Wellerhaus (1959); and Duursma (1959). We meet six main water masses (Fig. 2). The North Atlantic dee water (NT) is the only one to originate in th section. In deep-going winter vertical convection reaches down as far as 3,000 m from the surfac Furthermore, there is the Gulf Stream water (G the water of the Labrador Current (L), and th East Greenland Current (OG), and of the Irminge Current (I), which makes a detour across the Ea Atlantic after having parted from the Gulf Strea water, and finally the Subpolar Bottom Water (SB).

The distribution of temperature decisively deter mines the distribution of density, and therefore th distribution of pressure and the currents. The iso

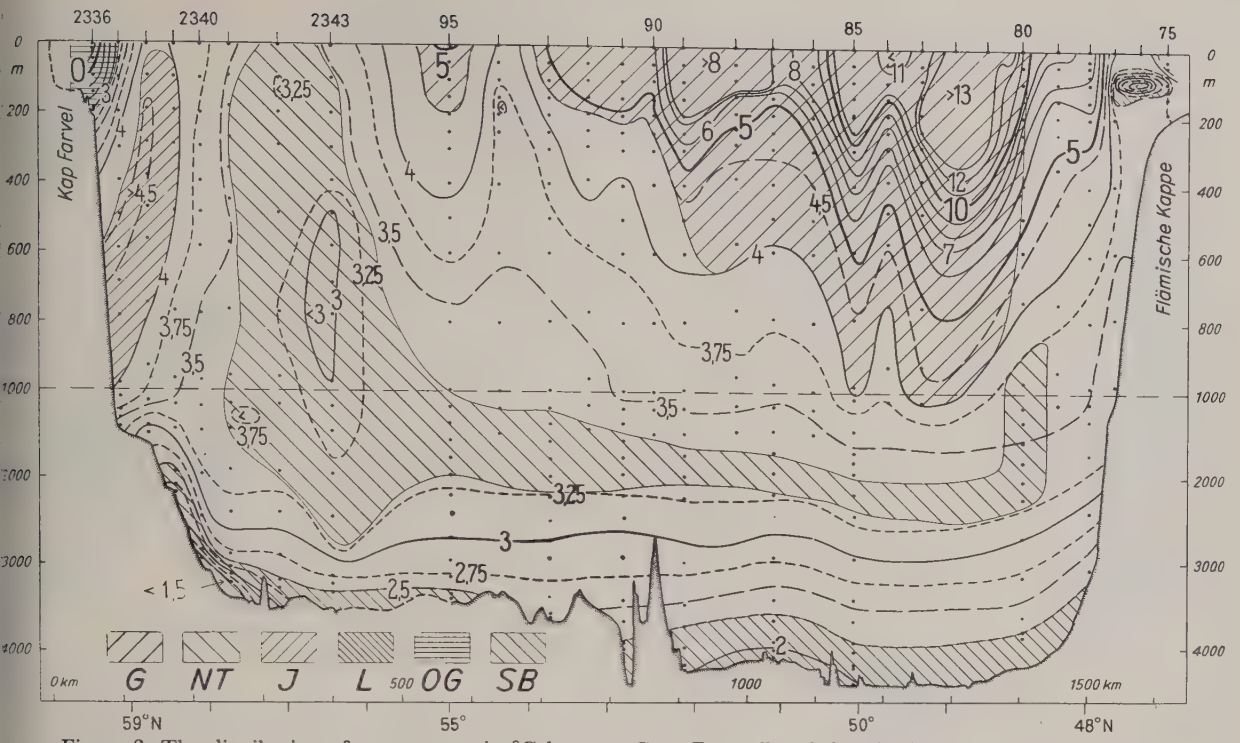

Figure 2. The distribution of temperature in °C between Cape Farewell and the Flemish Cap late in winter 1958 (after Koopmann, 1959). (For location of the section see Fig. 1.)

herms at the surface give an approximate view of he current field in winter. The distribution of the rface temperatures in Figure 3, given by Koslow-i (1959), is therefore of special interest. In many gions it can be comprehended only incompletely om our temperature registrations. This becomes ident from the many interrupted isotherms. How-er, it is certain that south of the Newfoundland ank the Gulf Stream turns to the north. Part of it turns to the south in a counter current like a great ldy; another part turns eastward in 50—52°N, osses the Mid-Atlantic Ridge in about 52°N as is own by the closing together of the isotherms, and en spreads in a broad ribbon towards Iceland and a second ribbon towards Ireland. It is obvious that e observations made in winter, especially, should be llected together completely. They should, however, reduced to a fixed date, for which we chose the April. Thanks to the daily observations of the Atlan- weather ships this was possible. The annual vari-ions of the surface temperature (Fig. 4) show that e Polar Front Survey sampled quite well the annual treme values by means of the observations made in larch/April and August/September. The comparison the winter section and the summer section makes it ident to what degree the warm surface layer masks the field of temperature of deeper layers. It is therefore not permissible to draw conclusions about the currents from the surface isotherms in late summer.

After this survey let us again return to the winter section between Cape Farewell and the Flemish Cap (Fig. 2). Special attention should be paid to the deep-reaching vertical convection. The cold water in this section is at the same time of a relatively low salinity. The best proof of the effectiveness of the deep-going vertical convection in winter, however, is the high amount of oxygen in the whole water column. The percentage of oxygen saturation on this winter section is shown in Figure 5. Whenever one wants to pass from a selected vertical section to the horizontal distribution of hydrographical factors difficulties arise. (This is where the task proper of a comprehensive exploitation has to be started.) In spite of this we can try to limit the region of deep-going vertical convection. To do this the depths at which the temperatures are lower by 1°C than they are at the surface are shown in Figure 6. Thus the region of nearly homogeneous temperature in winter can be seen. Within the area investigated by us the processes of sinking reach their greatest depth south of Greenland in parts of the vertical section between Cape Farewell and the Flemish Cap. In this area is

Figure 3. The distribution of surface temperature in °C in the northern North Atlantic late in winter 1958 (After Koslowski, 1959).

the origin of the North Atlantic Deep Water which can be traced as far as the South Atlantic Ocean.

The process of sinking does not reach the ocean bottom. We there find very cold water which comes from the Greenland Sea and crosses the Greenland-Iceland Ridge. It is distinguished by the fact that as a rule, it follows the continental slope of Greenland and does not run along the axis of the West Atlantic Trough (Fig. 7). We can trace the core of the cold water mass by systematic observations near the bottom made late in the summer of 1958. A map representing the edge of the shelf, the axis of the cold bottom water, and the axis of the West Atlantic Through clearly reveals that the axis of t cold bottom water runs between the two enclosi lines (Fig. 8). If we trace this axis of cold botto water in a longitudinal section, the changes of te perature near the bottom can be followed over mo than 1,200 km (Fig. 9). There remains a co paratively thin layer varying between 50 and 100 in thickness. Here we have the counterpart of t overflow of the Iceland-Faroe Ridge. The overflow the Greenland-Iceland Ridge is, however, strong and has a wider range. The difficulties in observing are by no means easier to overcome than tho which we will have to face in the Overflow Pr

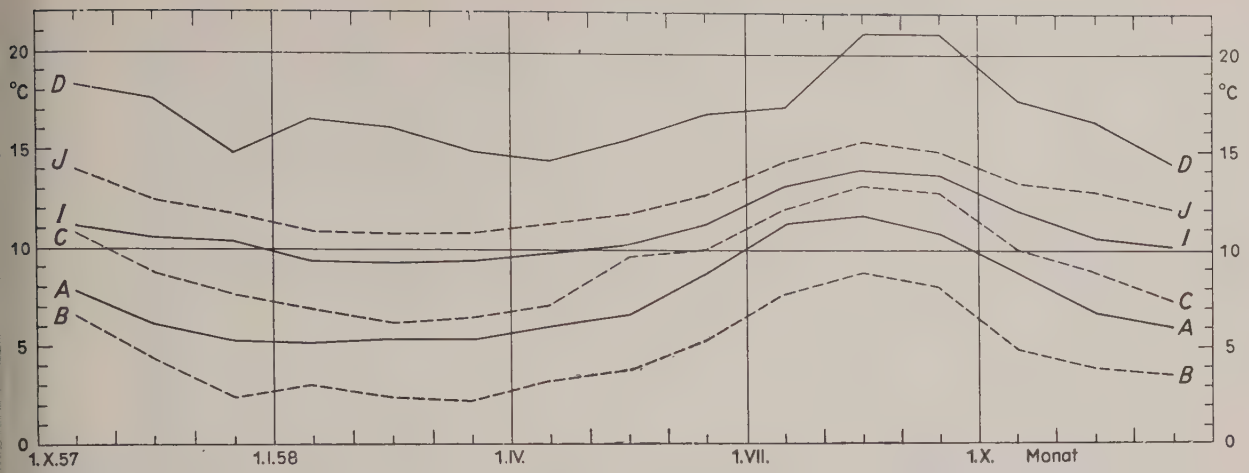

Figure 4. Annual variations of the surface temperatures observed by the North Atlantic weather ships 1957/1958 (after Koslowski, 1959).

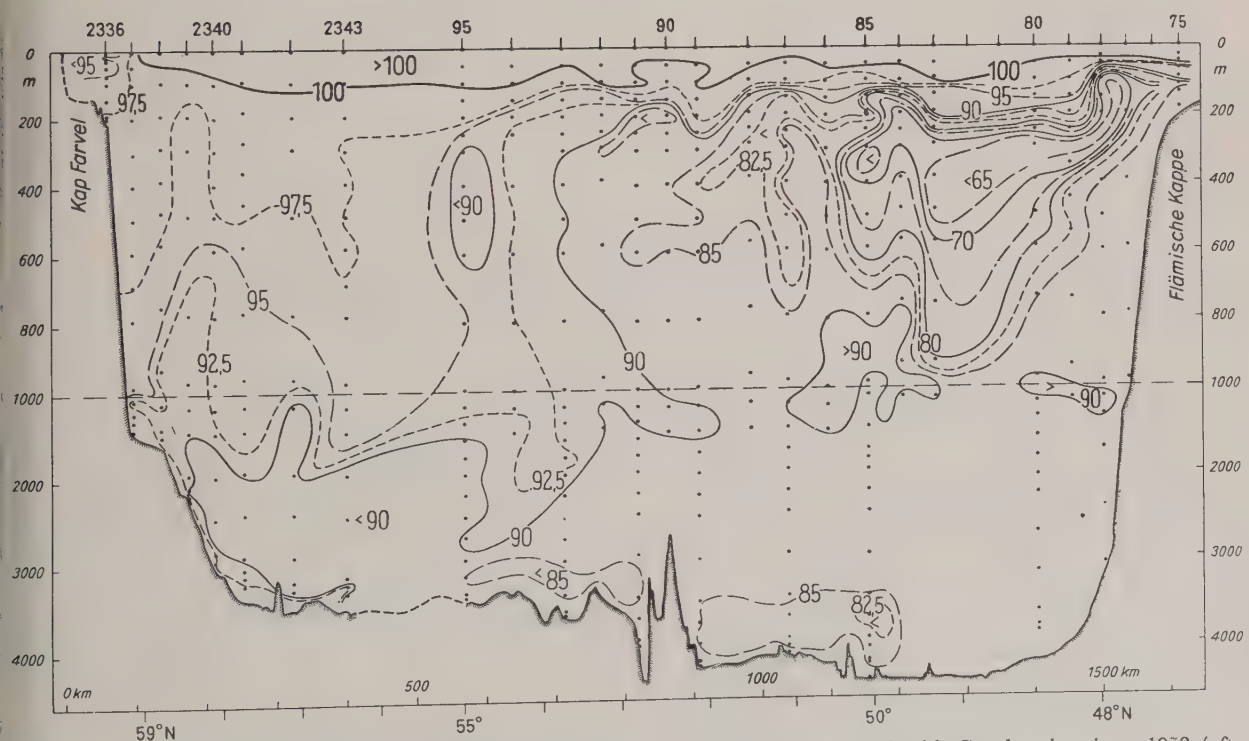

Figure 5. The distribution of oxygen (% saturation) between Cape Farewell and the Flemish Cap late in winter 1958 (after Beck, Kalle, & Rogalla, 1959). (For location of the section see Fig. 1.)

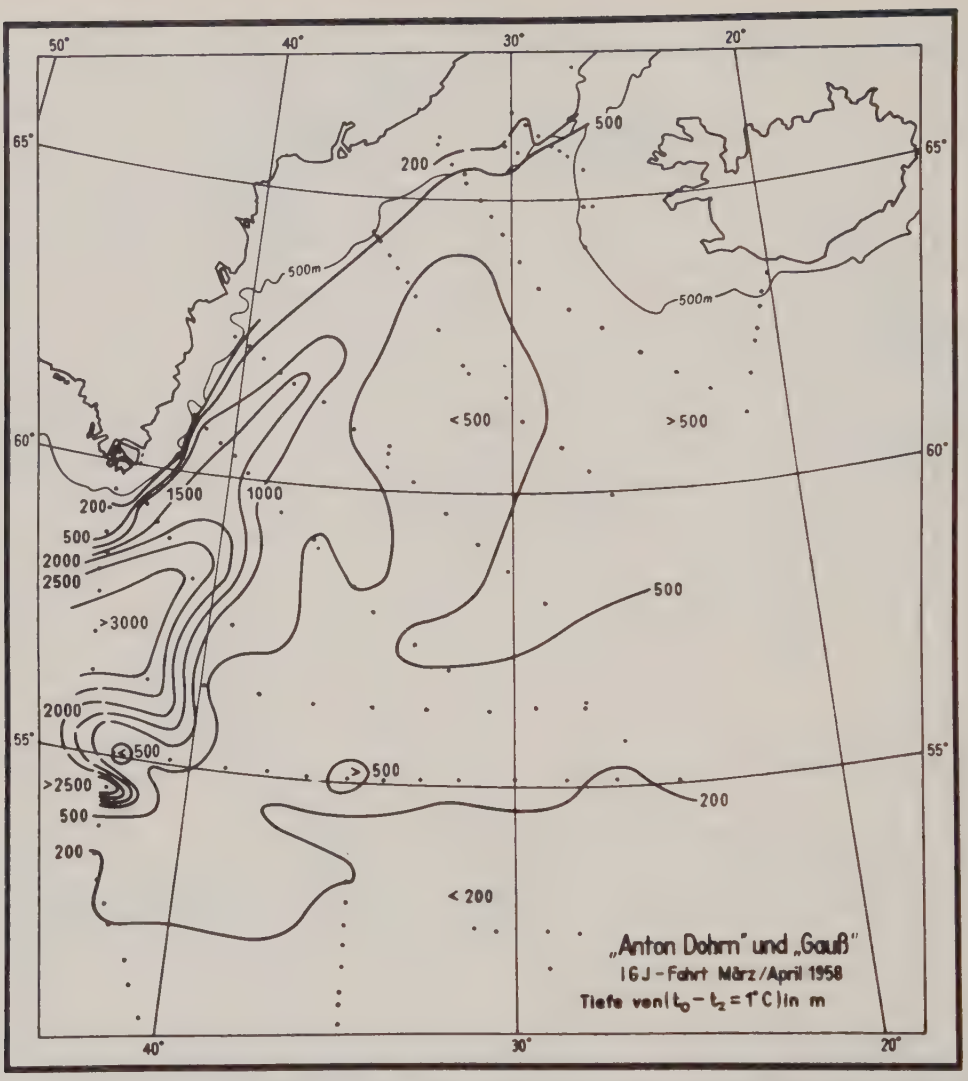

Figure 6. Depths with temperatures by 1 °C lower than those at the surface in the northern North Atlantic late in winter 195

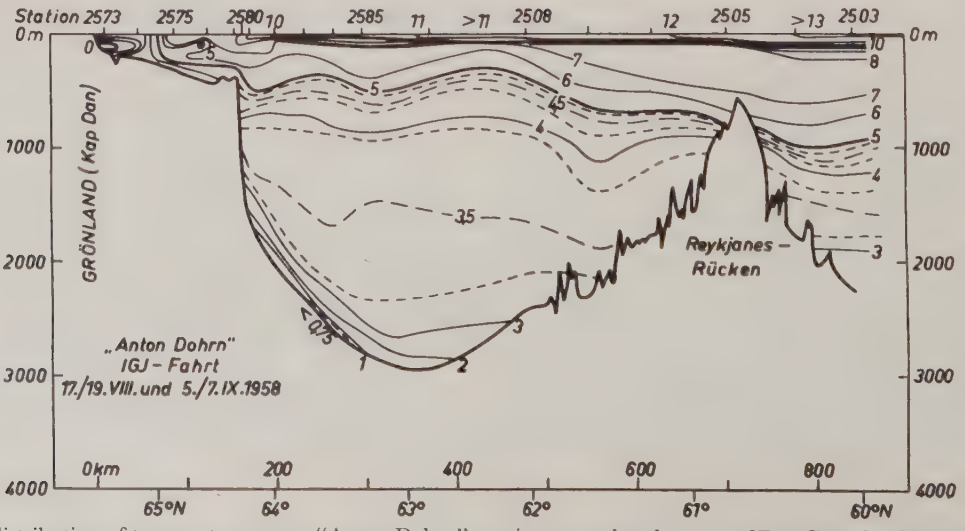

Figure 7. The distribution of temperature on an "Anton Dohrn" section normal to the coast of East Greenland late in summer 1958

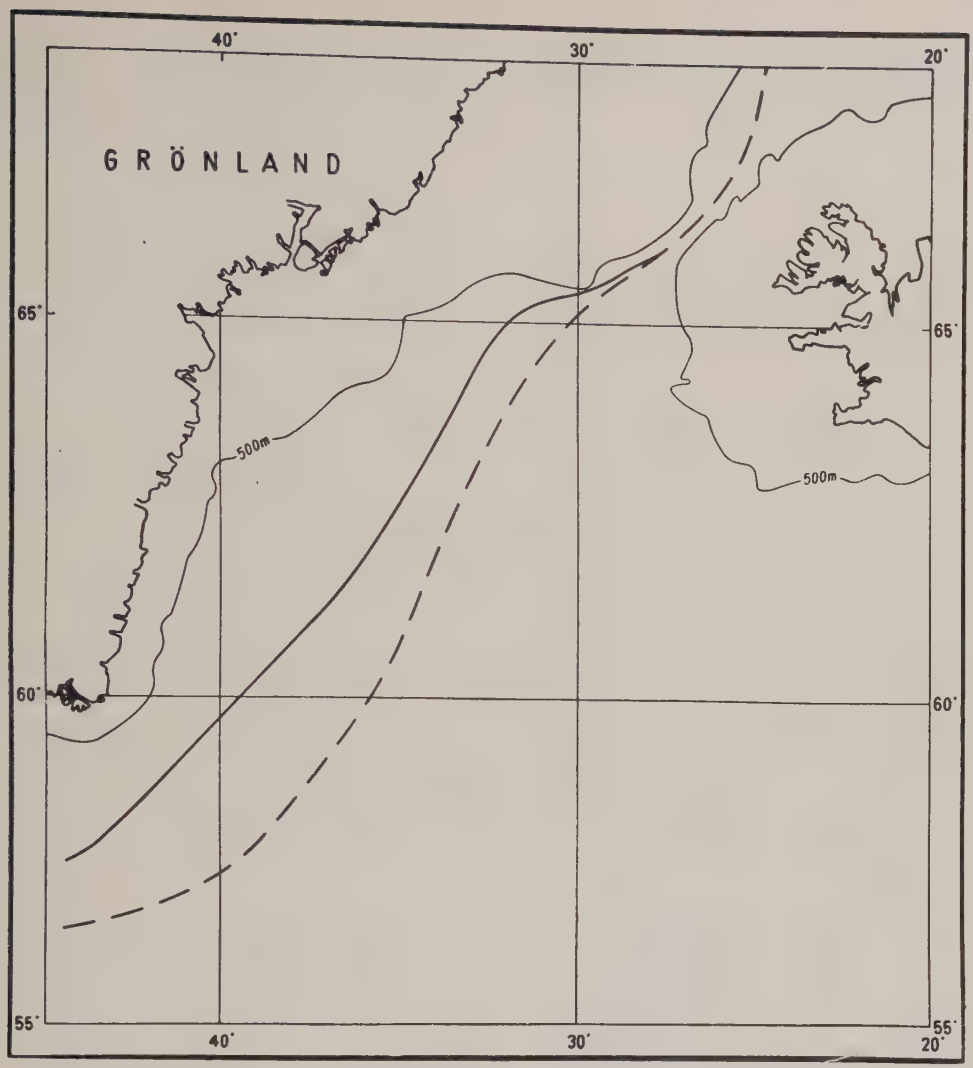

Figure 8. The location of the edge of the shelf, the axis of the West Atlantic Trough (- - -), and the axis of the cold Subpolar Bottom Water (—) late in summer 1958.

gramme 1960. Our section ends south of Cape Farewell. What happens to this bottom water on its way between Cape Farewell and east of the Newfoundland Bank may perhaps be deduced from the observations of other participants of the Polar Front Survey. Again and again our expectations demand the seventh step mentioned above, a final comprehensive exploitation of the observations made in the Polar Front Survey 1958.

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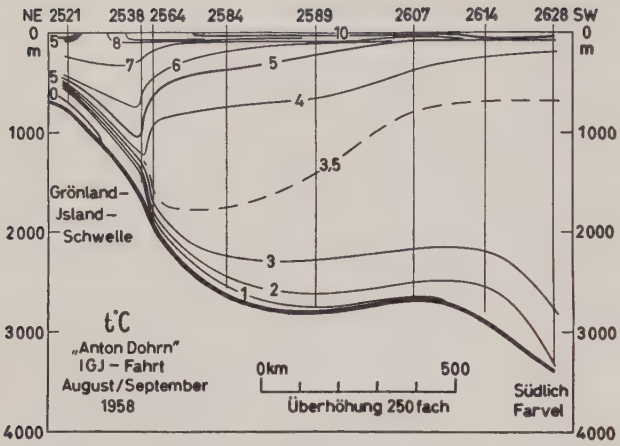

Figure 9. The distribution of temperature late in summer 1958 on a longitudinal section following the axis of the Subpolar Bottom Water. (For location of the section see Fig. 8.)

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17.

Vertical and Horizontal Movements in the Ocean Derived from Work during the IGY

By

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Marine Biological Laboratory, Plymouth, England

Summary

The material of this paper was first presented at the International Congress of Oceanography at New York by whom it will published.

An experimental investigation at one station, Cavall, in the Bay of Biscay, at 46°30'N, 8°00'W is described.

Working from a ship which cannot maintain a vertical wire angle during windy weather, a hoist of bottles may rise and fall in the water while the messenger is running. Such "vertical yawing" leads to serious error in the relation of temperature to depth, to salinity, and to oxygen content. Errors in depth due to this cause may exceed 20 metres and the scatter of observations around a T/S curve derived by the method of least squares is much increased.

To prevent oxygen absorption by corrosion spots, our water bottles have been coated with an epoxy-resin-Araldite.

Data collected from the deep water at Station

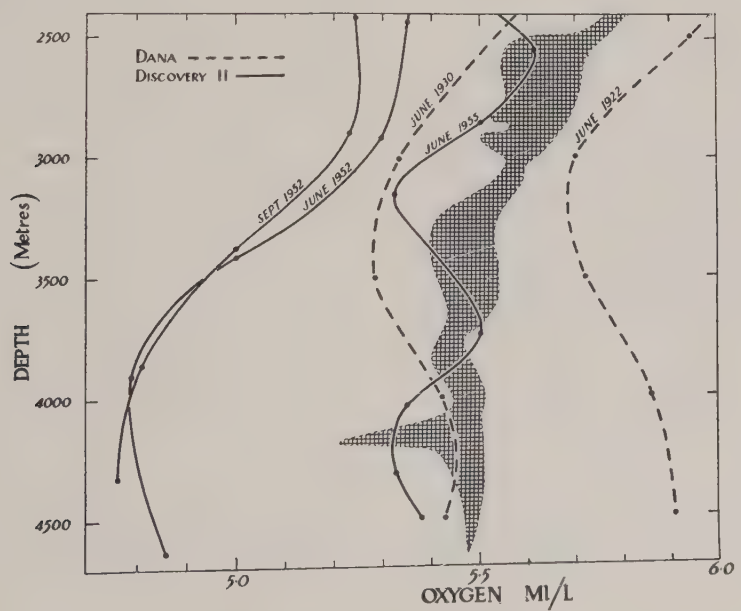

Figure 1. Station Cavall below 2,500 m. To illustrate the change in oxygen content with time. The cross-hatched envelope includes all observations from four cruises in 1958. The observations in 1922 and 1930, almost certainly from uncoated water bottles, may be too low. The other observations were from coated water bottles.

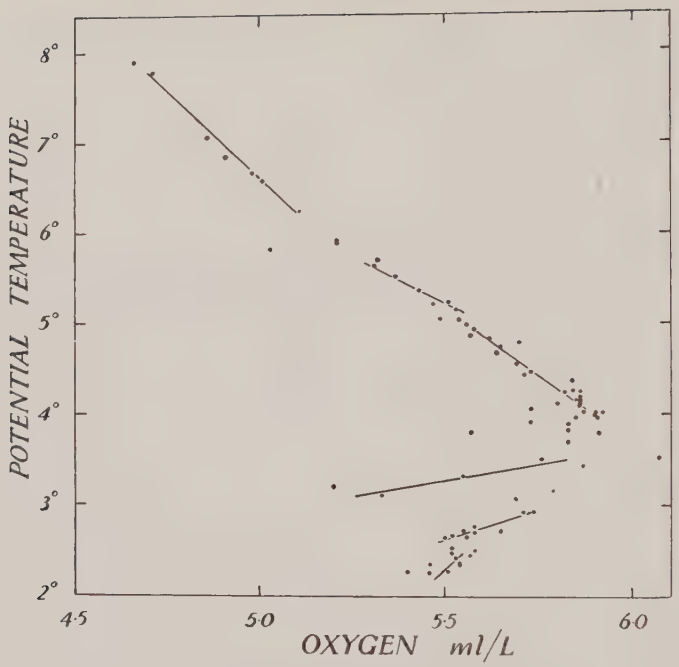

Figure 2. Station Cavall, March, April, and September 1958 combined. Curve fitting by method of least squares of oxygen/potential temperature observations.

Cavall show that from 1922 to 1952 there was a fall in oxygen content of 1 ml/L, but that by 1955 half of this fall had been recovered (Figure 1).

A number of linear curves may be fitted to the potential temperature-salinity data. These curves lie along isopycnal surfaces, i. e. they represent water masses in adiabatically neutral equilibrium. To these water masses linear curves relating dissolved oxygen to potential temperature may also be fitted (Figure 2). They have been termed "resident water masses" to suggest that they have had long residence in the deep North Atlantic. They have potential densities 27·831, 27·862, 27·890, and 27·903.

The resident water masses each in adiabatically neutral equilibrium are separated from each other by a number of narrow zones, which have been variously thought of as discontinuity layers, zones of conflict, laminated or lenticular intrusive plates, discontinuity platforms, glide planes, or as "complexes", according to my changing approach to the data. These descriptive terms epitomize different facets of extremely complicated systems. Within these zones there is a sharp increase in density and curve fitting of data has proved impossible. The results, at first chaotic, crystallized to a picture coherent with previously published hypotheses.

The "complexes" which occupy the discontinuity layer are interpreted as the final stages of boluses descending from the Iceland-Faroe Ridge, coming to rest on their appropriate discontinuity platforms and then spreading out as a complex of very thin laminated plates along the glide planes.

A series of riders suggest (a) that most neutral buoyancy floats are likely to come to rest at one of the discontinuity platforms rather than within one of the resident water masses in neutral adiabatic equilibrium; (b) that the resident water masses are likely to be biological deserts; (c) that animals are likely to be concentrated in the complexes where both vertical and horizontal transport concentrate their food; (d) that each complex may prove to carry distinctive biological indicator species; (e) that the "oceanographic age" of complexes will be difficult to establish; (f) that the complexes or glide planes complete my hypotheses to correlate fluctuations in fisheries productivity in shallow seas with fluctuations in Arctic climate.

18.

Observations Hydrologiques Effectuées par "L'Aventure" en 1957 et en 1958 au Nord du 48ème Parallèle*)

Par

G. Peluchon

Service Hydrographique de la Marine, Paris

Résumé

Dans cette communication sont présentés sous forme graphique les premiers résultats des observations hydrologiques recueillies par l'Escorteur "l'Aventure" dans l'Atlantique Nord en 1957 et 1958.

1° – Une coupe du Détroit de Davis comportant 9 stations réparties sur le 66ème parallèle et effectuée du 21 au 23 Août 1957.

Le tracé des isothermes et isohalines met en évidence l'existence de masses d'eau dont les caractéristiques indiquent l'origine: eau en provenance du sud, le long du socle groenlandais ainsi que près du fond dans l'axe du détroit, eau en provenance de la mer de Baffin le long des côtes de l'Ile de Baffin. L'eau de fond de la mer de Baffin est caractérisée par les valeurs suivantes

$$t = -1{,}65°\text{C},\ S = 33{,}60\ {}^{0}/_{00},\ d = 1{,}027.$$

2° – Une coupe Ecosse-Groenland réalisée du 28 Août au 2 Septembre 1958 et comportant 10 stations.

On constate que le Gulf Stream fait sentir son influence en surface jusqu'au delà du 30ème méridien Ouest. En profondeur, on décèle l'existence d'un flux général dirigé vers le Nord entraînant des eaux d'origine Nord Atlantique, sauf dans la partie la plus à l'ouest de la coupe où ce mouvement vers le nord intéresse des masses d'eau plus froides et moins salées qui ont été formées dans la mer d'Irminger par apport dû au courant Est groenlandais, lequel semble bien localisé le long du continent groenlandais.

3° – Deux coupes de l'Atlantique Nord:

(a) Terre-Neuve – Brest, comportant 21 stations, effectuée du 11 au 22 Octobre 1957.

(b) Labrador–Brest, comportant également 21 stations, effectuée du 14 au 24 Octobre 1958.

On reconnait sur ces coupes, d'ailleurs assez écartées l'une de l'autre, la présence des courants du Labrador plaqué à l'ouest contre le plateau continental, et du Gulf Stream, beaucoup moins caractérisé. La limite assez nette des eaux "Nord Atlantique" se situe sensiblement sur le méridien 33° W, bien à l'ouest de la dorsale Nord Atlantique (30° W).

Une étude dynamique des courants est esquissée, qui suggère l'existence de méandres du Gulf Stream dont l'amplitude irait en décroissant d'ouest en est.

*) Publié dans la série *Cahiers Océanographiques, 12* (2): 111–18.

19.

Canadian IGY Project "Deep Water Circulation" North Atlantic, 1958

By

N. J. Campbell

Fisheries Research Board of Canada, Atlantic Oceanographic Group

The Atlantic Oceanographic Group joined the International Geophysical Year survey "Deep Water Circulation" in 1958 in the offshore region between Bermuda and Baffin Bay.

Forty-nine oceanographic stations were occupied from C.N.A.V. "Sackville" during the survey period July and August. Observations and chemical analyses which were conducted at sea, included routine marine and weather observations, oxygen, phosphate, nitrite, and silicate. Biological collections were made for th full extent of the cruise.

Salinities, temperatures, and silicate content wer found to be highest between Bermuda and the Gran Banks, while the oxygen and phosphate concentra tions were highest in Davis Strait. The nitrite con tent was very low and spotty in all offshore region except over the Davis Strait Ridge.

20.

Canadian Serial Temperatures and Salinities Relative to IGY Sea Level Recording, North Atlantic 1957–1958

By

L. M. Lauzier

Fisheries Research Board of Canada, Atlantic Oceanographic Group

The "Sea Level Recording" project of the International Geophysical Year called for observations of serial temperatures and salinities, at regular intervals, off Halifax, N. S. and off St. John's, Newfoundland. The temperature and salinity observations, from the surface to the bottom, involved the Atlantic Oceanographic Group, St. Andrews, N. B. and the Biological Station, St. John's, Newfoundland, of the Fisheries Research Board of Canada, and the Naval Research Establishment, Halifax, N. S. of the Defence Research Board of Canada. The actual continuous operation of sea level recording stations during the IGY was under the supervision of the Hydrographic Service of Canada.

Off Halifax, N. S., temperature and salinity observations were made once a month from July 1957 to June 1958, and also in October and December 1958, and in January 1959. The station was located sixteen miles off the coast, with a depth of water of 130 metres. Off St. John's, Newfoundland, temperature and salinity observations were made at a station three miles off the coast, with a depth of water of 175 metres. From July 1957 to December 1958, the station was occupied twenty-seven times; at least once a month, and fortnightly from the middle of March to the middle of August 1958.

Temperature and salinity data collected during the International Geophysical Year for the "Sea Level Recording" project are tabulated. Reference is also made to other Canadian records which are available for study.

21.

Results of Current Measurements by Towed Electrodes in the Northern North Atlantic during the IGY

By

Hartwig Weidemann

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Methods, Instruments, Technique

It is ten years since von Arx (1950) published his paper on a method for measuring ocean currents from ships under way by means of towed electrodes, or as he called his apparatus, the Geomagnetic Electro-Kinetograph (GEK). Since that time this method has become familiar to most oceanographers, so that it will not be necessary to give a description of the theory and technique in this short paper (see Longuet-Higgins, Stern, and Stommel, 1954).

The equipment used by the German research vessels "Gauss" and "Anton Dohrn" was manufactured in various countries.

Recorder: "Speedomax" recording millivoltmeter with special GEK circuit (Leeds & Northrup, Philadelphia, U. S. A.).

Cable: Delivered by Tréfileries & Laminoirs du Havre, Paris: this cable is not affected by errors like "cable droop" and "windage" which were observed by Knauss and Reid (1957) with heavy cables and buoyant types respectively.

Electrodes: By Cambridge Instruments Co., London. (Ag—AgCl).

As the method gives only one component of the current (at right angle to the ship's course) it is necessary to use special course patterns for getting regular checks of the full current. We preferred a simple scheme which consisted of: —

50 min. on the general course,
10 min. at 45° to one side,
50 min. on the general course again, and
10 min. at 45° to the other side.

In this way we got hourly full current measurements without losing more than 5 % time.

On "Anton Dohrn", which had to work mainly in the waters between Iceland and Greenland, the cable was towed during nearly the whole time of the two cruises, except when the ship was passing ice fields in the East Greenland Current and on some other occasions such as in heavy seas or when there was damage to the cables. On "Gauss", however, the GEK was only rarely used. That is why the following results are only based on the "Anton Dohrn" measurements.

Results: Variability, Relation to Wind

The records in the main working region between Iceland and Greenland were often unsatisfactory for two reasons: first, this region is one of the main mixing areas where the waters of the East Greenland Current and those of the Irminger Sea (which are themselves a product of mixing processes) are in very turbulent motion, forming eddies of all sizes. This was shown not only by the very irregular records of the GEK but also by the underway records of the surface temperatures and salinities. So it was not possible in most cases to localize exactly the eastern boundary of the East Greenland Current, the temperature changing several times from warm to cold and back to warm when crossing from east to west. The second reason was the extraordinarily frequent occurrence of geomagnetic disturbances which unfortunately are particularly intense in these regions near the Polar Circle and which are most adverse to exact GEK measurements. From statistics of the Geomagnetic Observatory, Wingst, of the German Hydrographic Institute, it has been found that during the 89 days on which the electrodes were towed by "Anton Dohrn" only 25 were quiet against 64 magnetically disturbed: 13 days of the latter had magnetic storms or other heavy disturbances.

In order to get an impression of the constancy or variability of the recorded currents and of the representativity of a single measurement, a special

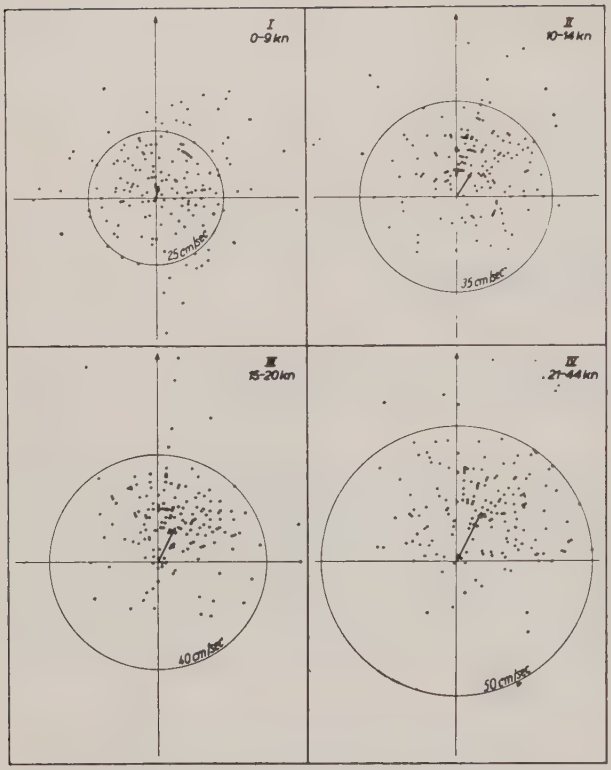

Figure 1. Current observations and mean current vector for 4 wind groups.

30-hour station was made in a relatively undisturbed region, 120 naut. miles south of Reykjanes, Iceland on the eastern slope of the Reykjanes Ridge. These measurements have been discussed in detail in another paper (Weidemann, 1959); therefore, the results will only be summarized here. There was obviously a typical wind-driven current with a deflection of about 30° *cum sole* from the direction of the wind and a speed in cm/sec. of nearly the same size as the velocity of the wind in knots. This wind drift had superimposed upon it periodic fluctuations of different periods. A periodographic analysis of the two components showed periods near the inertia period and others which may be interpreted as seiches. Tidal components were only to be seen in the record of the east-west component. The thermocline showed fluctuations of the kind due to internal waves; it may be that there was some influence on the GEK signals by these movements, too.

Knowing these results and the difficulties originating from geomagnetic disturbances and from eddies or mixing processes, it would have been useless to give a detailed chart of the single current vectors along the ship's courses. As the number of current fixes seemed sufficient (after cancelling those which were no evaluable there remained more than 600), however to promise reasonable mean values, the measurements were divided into 4 groups according to the wind force in order to obtain some relations between wind and current: —

Group	Force	Knots
I	0—3	0—9
II	4	10—14
III	5	15—20
IV	6 and more	21—44

Each of these groups contained nearly the same number of observations (between 130 and 170). The single current vectors were plotted in a diagram for each group in such a way that the direction was given as the difference from the direction of the wind; for instance, a current flowing to the east with a south wind was plotted as 90°, the same current with a north wind as 270°. Only the ends of the vectors being marked, the resulting diagrams became four clouds of points (Fig. 1). Those points which obviously did not belong to the clouds were left out; in practice by drawing circles of different diameters according to the different wind velocities and cancelling all points outside these circles. The centres of the clouds were now calculated vectorially. The results are given in Table 1.

Table 1

Group	I	II	III	IV	Total
Wind force (Bft.)	0...3	4	5	6...9	(5)
Wind velocity (knots)	0...9	10...14	15...20	21...44	0...44
Mean wind velocity (knots)	5·5	12·2	17·2	26·5	16·1
Mean current velocity (cm/sec.)	4·3	10·2	14·4	19·9	12·7
Mean angle of deflection *cum sole*	12·1°	33·0°	26·4°	27·0°	27·0°
Ratio current to wind (cm/sec. to knots)	0·785	0·839	0·836	0·750	0·790
Ratio current to wind (equal dimensions)	0·0152	0·0163	0·0162	0·0146	0·0153

The mean geographic latitude of the measurements being about 60°, these ratios have to be reduced by multiplying by $\sqrt{\sin \varphi} = 0{\cdot}93$ to the following values: —

Group	I	II	III	IV	Total
Ratio $\frac{\text{current}}{\text{wind}}$ (independent of latitude)	0·0141	0·0152	0·0151	0·0136	0·0142

These figures are obviously somewhat higher than the value used mostly which is 0·0126 for a stationary wind-driven current: it must be admitted, however, that there is some uncertainty originating from the so-called "k-factor" which is assumed to be an empirical function of the mean water depth by several authors. The deflection angles vary a little more, but they seem clearly to be smaller than Ekman's value of 45° for stationary drift currents.

Discussion

To explain these facts it is necessary to remember that the currents are compared with the actual wind without considering its duration before the observation. Therefore we must expect to get a relation differing from that for the stationary case. Ekman himself has given us a theoretical investigation of the behaviour of wind-driven currents a short time after the beginning of the wind. He has shown that the point of the current vector swings in a spiral around the final point of 45° for the stationary current, the period being half a pendulum day. In Figure 2 the values calculated from the "Anton Dohrn" measurements have been plotted according to their deflection angle and to their ratio to the "normal" value, which has been assumed to 0·0126 as above. It seems that the points fit quite well into this scheme, considering the great variations of the single values and the many uncertainties. On the other hand, the differences may be real: the values plotted in Figure 2 are the means of a number of different vectors corresponding to many different wind deviations and it can easily be seen from the nature of the spiral that the mean of a number of current vectors will not fall on the spiral itself but inside it, like points II, III, and IV.

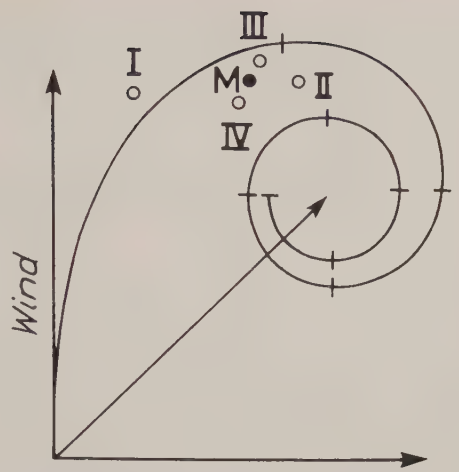

Figure 2. Ekman spiral for non-stationary drift currents with values calculated from "Anton Dohrn" observations (marks on the spiral for every 3 pendulum hours).

Summary

The results of current measurements by towed electrodes on "Anton Dohrn" in the Iceland/Greenland region during the IGY are discussed. In these mixing areas of polar and warm waters great turbulence was observed and, moreover, the records were often magnetically disturbed. A 30-hour test south of Iceland confirmed the variability of single measurements, showing fluctuations of different periods besides a typical wind drift. The uselessness of charts with single current vectors being so evident, the mean relation between wind and surface current was investigated. After dividing the more than 600 observations into 4 groups according to the wind force, the mean current vectors related to the wind direction were calculated. The results give deflections between 12° and 33° *cum sole*, mean 27°, and a ratio $\frac{\text{current}}{\text{wind}} \times \sqrt{\sin \varphi}$ of about 1·4 .... 1·5 %. Comparing these values with those for stationary wind-driven currents (45° and 1·26 % respectively), the differences may well be explained as being due to the non-stationary conditions in terms of the theory of Ekman.

Acknowledgement

We are very much indebted to the "Deutsche Forschungsgemeinschaft" whose considerable grants for the German IGY contributions made it possible to procure the equipment used in these investigations.

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22.

Danish Hydrographic Observations under the Polar Front Programme

By

Frede Hermann

The investigations from R/V "Dana" under the Polar Front Programme consist of two transatlantic sections (Fig. 1) and six sections in the Labrador Sea and Davis Strait (Fig. 4).

The first transatlantic section (Fig. 2) between the Faroes and East Greenland along 62°N was worked from 3. to 10. July 1958. The Reykjanes Ridge divides the section into two halves with different hydrographic features. The eastern half is filled to a depth of about 1,000 metres with warm saline water from the Gulf Stream System. Over the slope west of the Faroes a bottom layer with temperature below 3° is found. This water mass is assumed to consist of Norwegian Sea deep water, which has flowed out through the Faroe Bank Channel and mixed with Atlantic water underway. The same

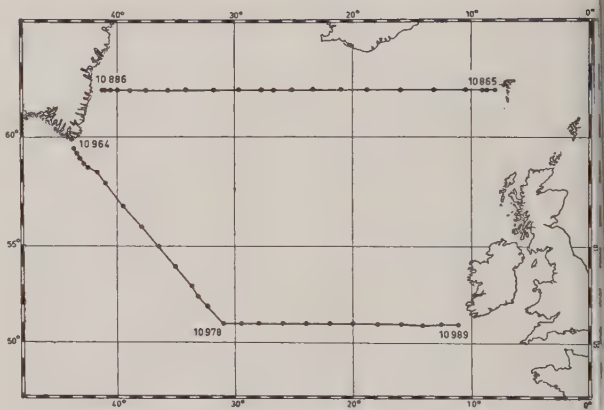

Figure 1. Location of transatlantic sections.

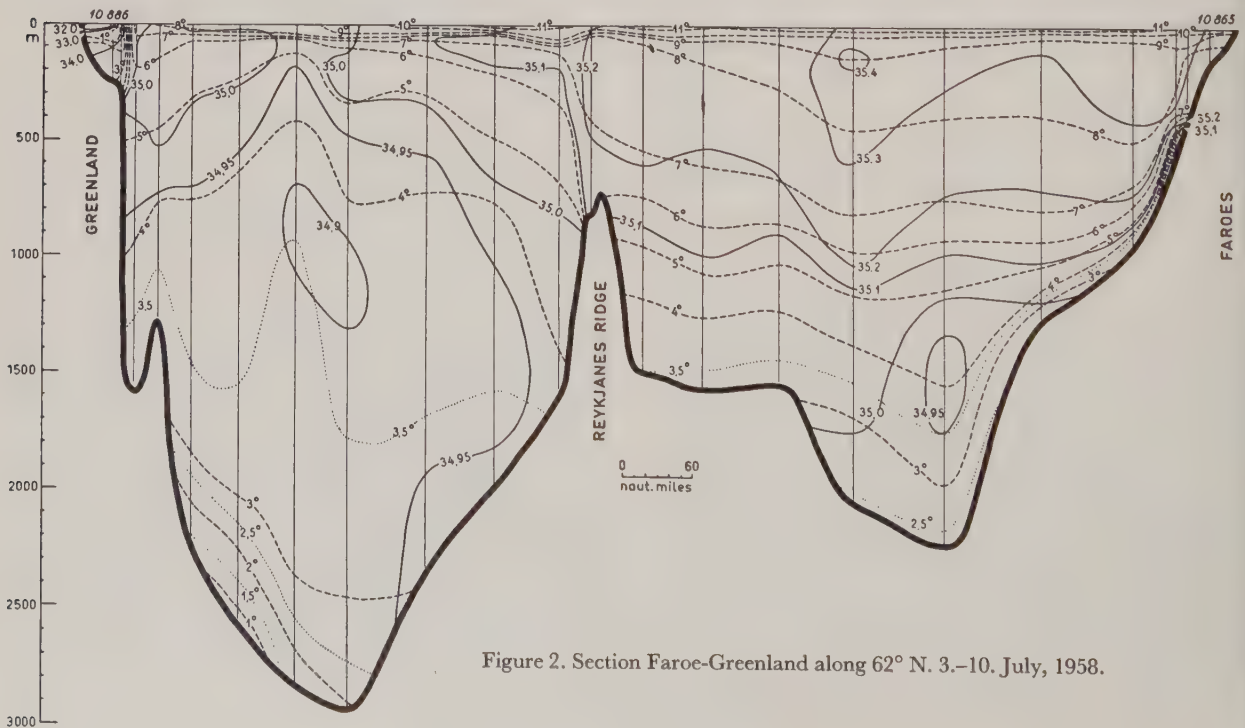

Figure 2. Section Faroe-Greenland along 62° N. 3.–10. July, 1958.

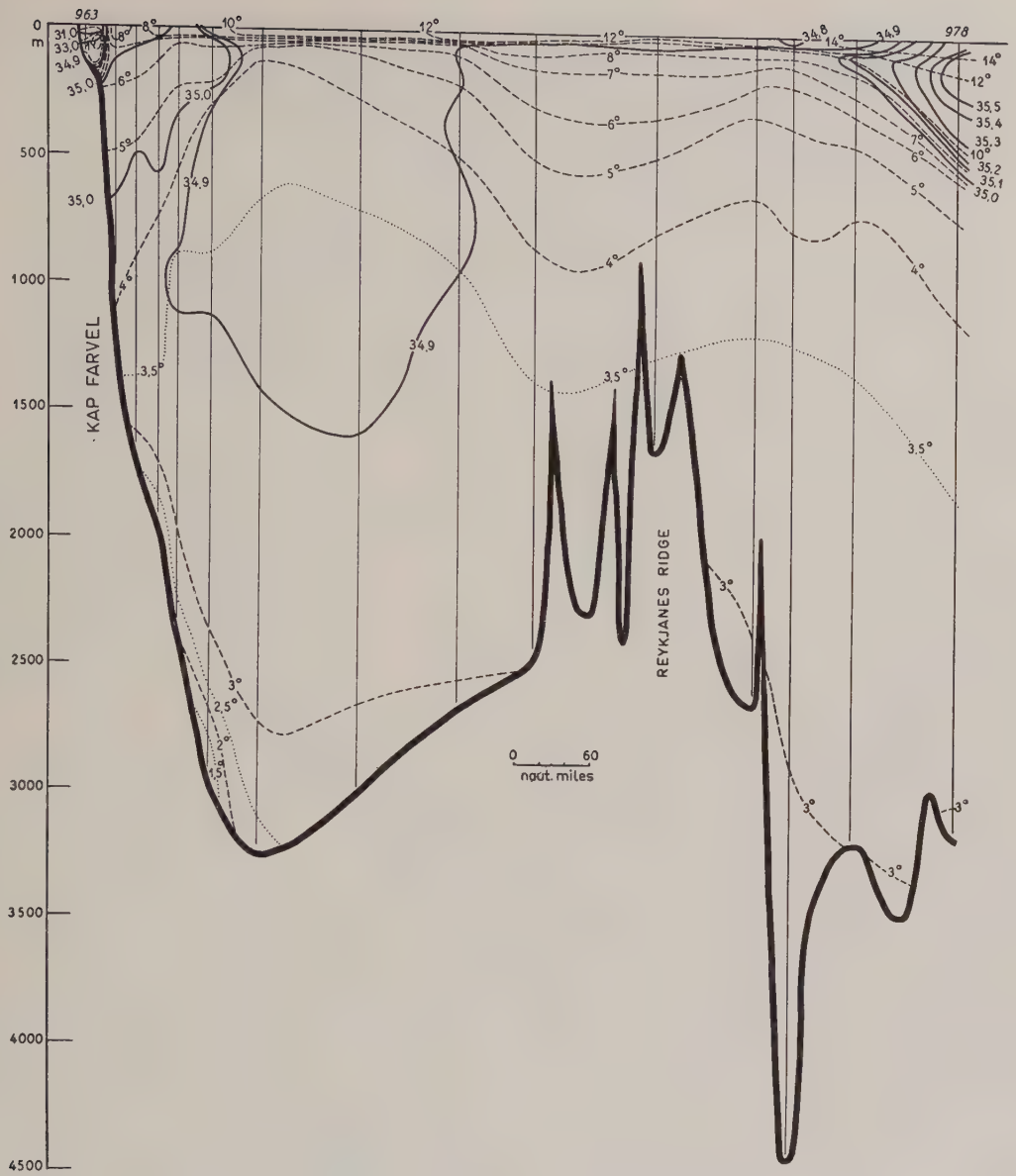

Figure 3a. Section Cape Farewell to Ireland. 15.–25. August, 1958.

old water mass is found further westwards at depths elow 1500 metres. This is assumed to be the ame current, which here has bent southwards. Over he plateau east of Reykjanes Ridge the bottom ater has a temperature below 3·5° and a salinity bove 35 ‰. This water type is probably formed y mixing of cold water overflowing the Faroe-celand Ridge and the overlying warm Atlantic water, ut it is hardly possible to distinguish between the ater masses from the Faroe Bank Channel overflow nd the Faroe-Iceland overflow.

The inclination of isotherms and isohalines and a t-S diagram analysis of the stations in sections 2 and 3 indicate that this cold bottom water flows south-westwards along the eastern slope of the Reykjanes Ridge up to its southern end, where a part of it bends northwards into the Irminger Sea. In the northern part of this sea it bends westwards again and later south-westwards along the East Greenland slope. Here it is found as an intermediate layer between the subarctic water and the very cold bottom water originating from the Iceland-Green-

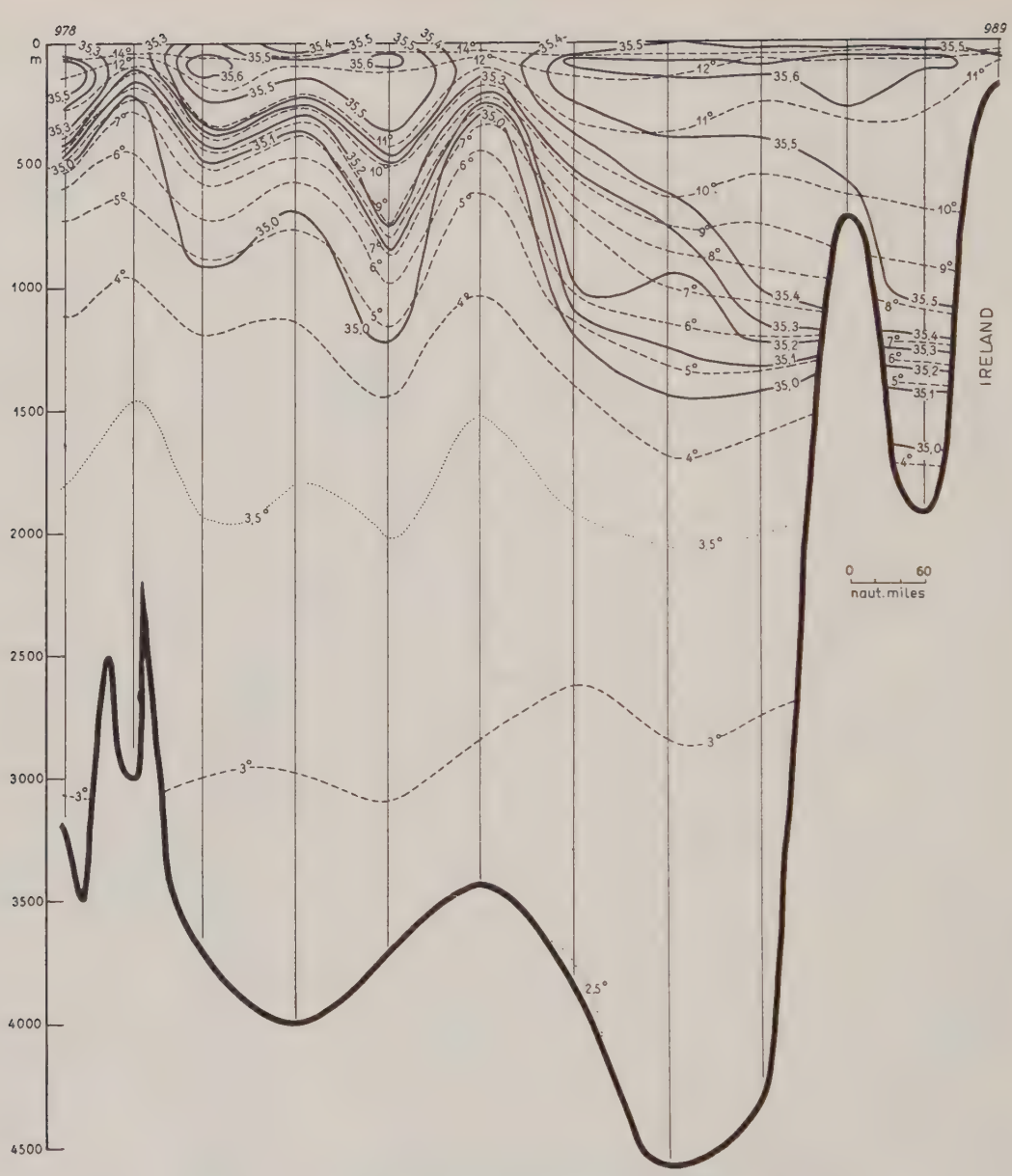

Figure 3b. Section Cape Farewell to Ireland. 15.–25. August 1958.

land overflow. Underway it is diluted by mixing with the two above-mentioned water masses, but the current can still be traced by a salinity maximum at the 3° isotherm. The strong inclination of the isotherms in the bottom layers off the East Greenland slope indicates strong south-going current.

West of the Reykjanes Ridge we find in the upper layers the north-going warm Irminger Current; the south-going branch of the same current is as usual found off the slope of East Greenland; and the East Greenland Polar Current is restricted to th shelf area which in this place is narrow. The ma part of the Irminger Sea is at this latitude fille with subarctic mixed water between depths of abo 1,000 and 2,000 metres. This nearly homogeneo water mass is formed by vertical mixing during th winter cooling in the southern Irminger Sea and th Labrador Sea.

The second transatlantic section (Fig. 3 a and b from Cape Farewell to 51°N, 31°W and from the

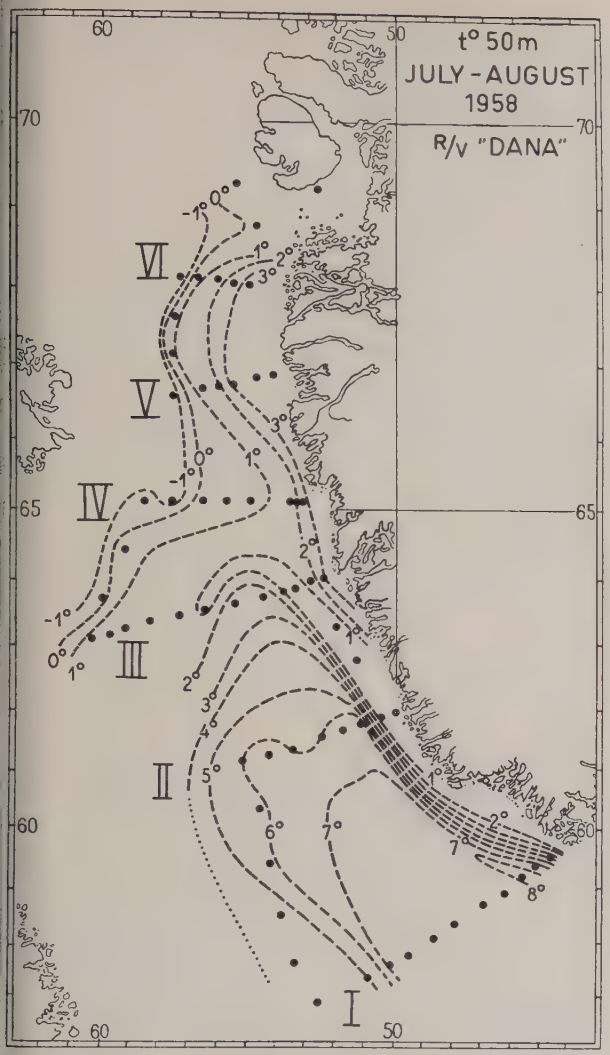

Figure 4. Location of sections and distribution of temperature at 50 metres.

o South Ireland was worked from 15. to 25. August 1958. In the north-western part of the section, between Cape Farewell and the Reykjanes Ridge, he same water masses as described in the northern ection are found. Over the Reykjanes Ridge and vest of it very great variations in depth are found; rom about 1,000 to 4,500 metres in a distance f only 150 miles. The front between the subarctic vater and the "Gulf Stream" water is found at bout 52°N, 32°W. In the eastern part of the section he subarctic water is found at depths between bout 1,000 m and 3,000 m. Below the subarctic ayer the bottom water with temperatures below °C is found. This water possibly originates from verflow over the ridges on both sides of Iceland.

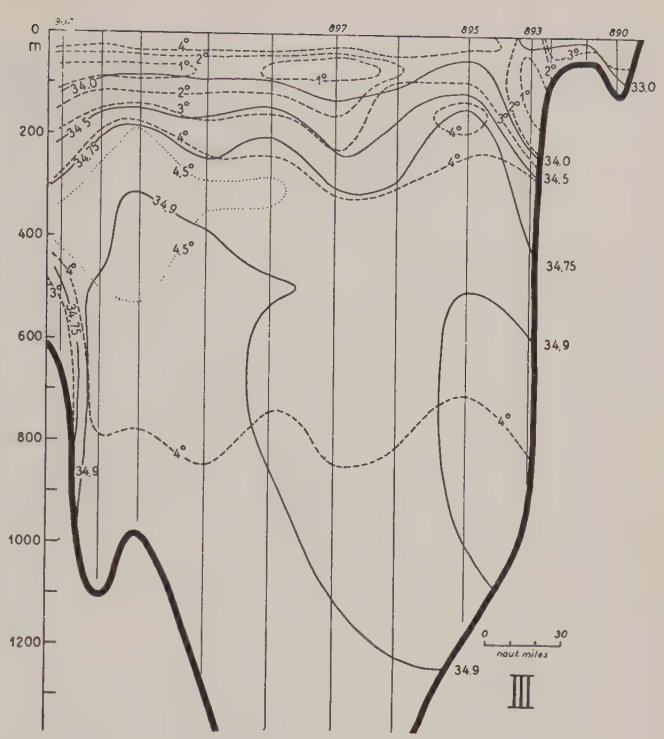

Figure 5. Section III across Fylla Bank. 17.–20. July, 1958.

The stations in the Labrador Sea and Davis Strait were worked between 17. July and 15. August. The station positions and the temperature distribution at 50 m are shown in Figure 4. The figure clearly shows the course of the main currents in this area. The polar component of the West Greenland Current is found nearest the West Greenland coast, until at about 64°N it bends westward. Outside the shelf the Irminger component of the current is found, mainly as an undercurrent. In the northern part of the area the sections intersect the Baffin Island Polar Current, where temperatures below — 1°C were met. The vertical distribution of temperature and salinity in section III is shown in Figure 5.

In the western part of sections III to V (Fig. 4) cold bottom water is found: this must originate from the Baffin Bay deep water which has overflowed the Davis Strait Ridge. The salinity and consequently the density of this cold bottom current is, however, so low that the current can hardly contribute to the renewal of the bottom water in the North Atlantic.

Besides temperature and salinity, inorganic phosphate was observed in the upper 100 metres and oxygen in the deeper water layers. Salinities of samples from depths below 1000 metres were determined by potentiometric titration.

23.

The Relationship between Potential Temperature and Salinity in Deep Atlantic Water

By

L. V. Worthington and W. G. Metcalf

Since 1954 and especially during the IGY the Woods Hole Oceanographic Institution has been engaged in a re-survey of the temperature, salinity, and oxygen of the Atlantic Ocean between 50°N and 32°S. Figure 1 shows the oceanographic stations occupied in connexion with this programme.

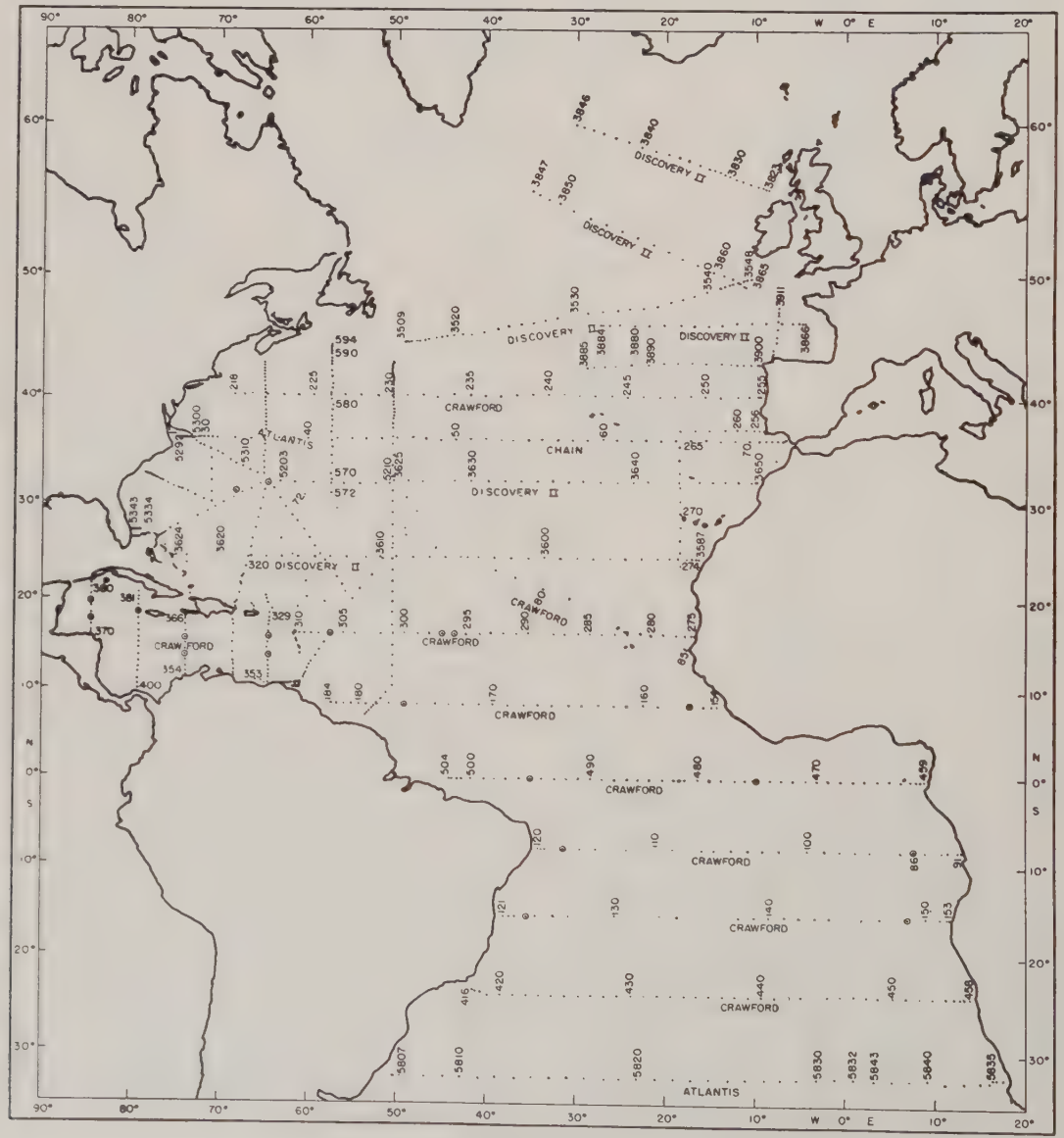

Figure 1.

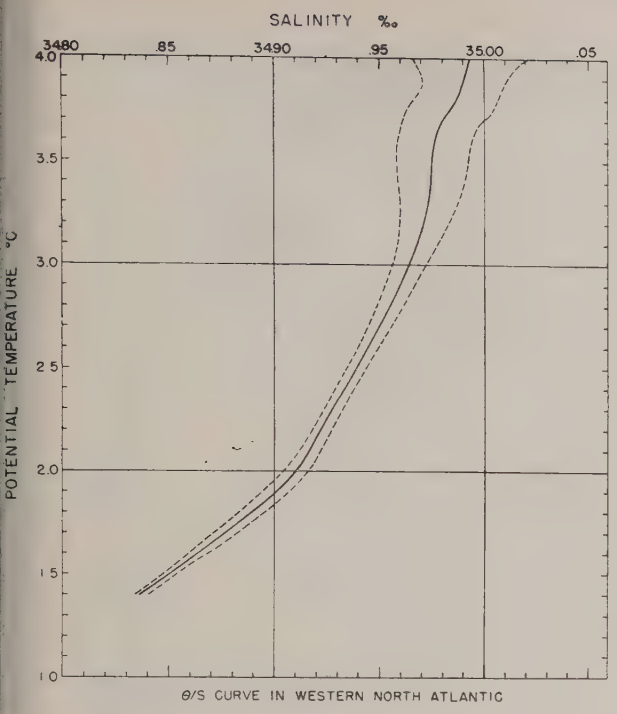

Figure 2.

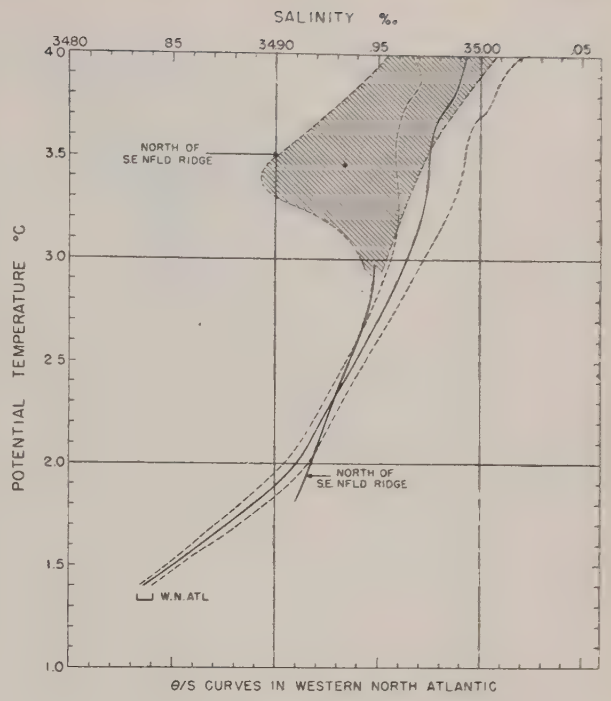

Figure 3.

The development by Schleicher and Bradshaw and by Cox of salinometers using conductivity bridges has made it possible to establish the reliability of the potential temperature versus salinity relationship in the deep water to a degree not previously possible. Figure 2 shows a Θ/S curve made up of 3,145 individual measurements below 4°C in water deeper than 1,000 m in the North Atlantic Ocean west of the Mid-Atlantic Ridge and south of the South-East Newfoundland Ridge. An envelope representing the standard deviation from the mean is shown surrounding the curve. Below 2·5° this deviation varies between ± 0·006 and ± 0·003 ‰ which is considered remarkably small inasmuch as three different salinometers, 12 operators, and 8 batches of Copenhagen Standard Water were involved in the work.

The inflection point at 3·5°C appearing in the curve showing almost no change in salinity with decreasing temperature can be traced to the Labrador Sea where there is a marked core in the form of an intermediate salinity minimum which is seen more clearly in a later figure. The change in the slope of the curve at 1·9° represents the transition from North Atlantic Deep Water to Antarctic Bottom Water.

Variations from the curve can be used after the method of Helland-Hansen as indicators of water movements, and many of the variations discussed here are so small that they would have remained undetected by conventional titration methods.

The Θ/S characteristics of the deep water north of the South-East Newfoundland Ridge can be seen in Figure 3 where it is compared with the western North Atlantic as a whole. A pronounced salinity minimum at 3·5°C is found throughout the Atlantic north of 40°. It is nearly always the most recently produced deep water in the North Atlantic and is formed in the Labrador basin. At the colder end of the curve, the water north of the South-East Newfoundland Ridge is more saline at the same temperature than the remainder of the western North Atlantic from which it is separated by the ridge.

In the eastern North Atlantic the core of relatively fresh water is most marked in the extreme north as shown in Figure 4, but it is perceptible as far south as 40°N where it gives way to Mediterranean influence which predominates between the 20° and 40° parallels.

Norwegian Sea overflow, which is found along the eastern slope of the Mid-Atlantic Ridge as described by Dietrich (1956), is also shown in Figure 4. It shows a high scatter and is as much as 0·08 ‰ more saline than the surrounding water in "Discovery's" section at 60°N.

South of 20°N the Mediterranean influence is felt less strongly, and at latitude 16° conditions are much the same as in the western basin. At 8°N

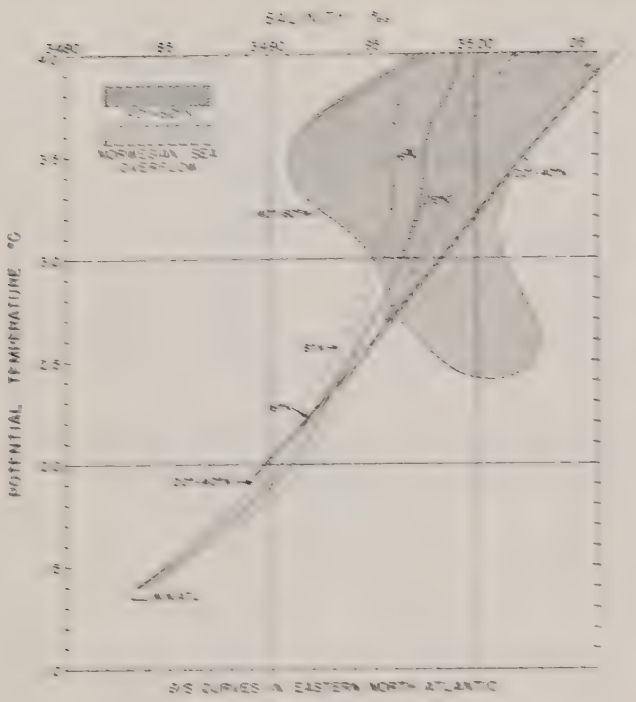

Figure 4.

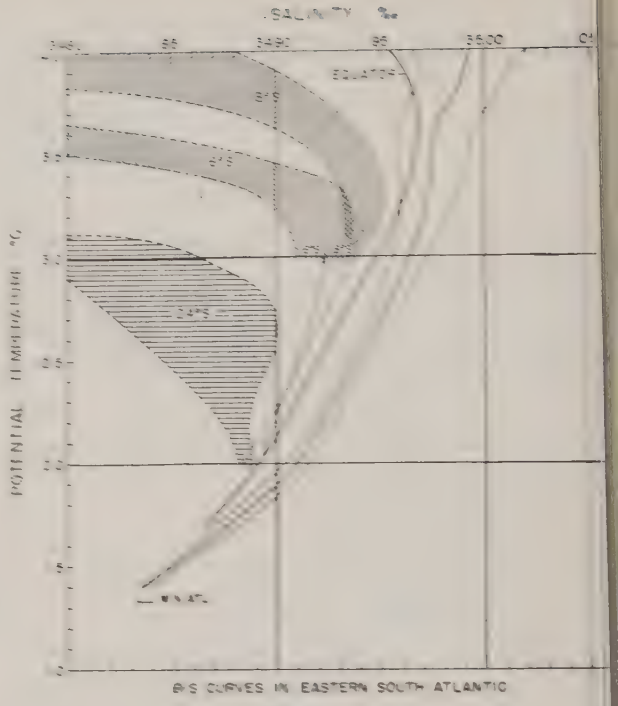

Figure 5.

the influence of the Antarctic Intermediate Water can be seen in the upper levels.

From the equator southward the effect of the Antarctic Intermediate Water is more and more deeply felt until by the 24°S parallel, water of North Atlantic origin is only perceptible at the bottom as shown in Figure 5.

The geographic distribution of the salinity variations is best described by the salinity anomaly chart as devised by Helland-Hansen (1926). In the ensuing figures the departures in salinity from the western North Atlantic average curve have been contoured at intervals of 0·01 ‰. For convenience, the contour labelled 2, for example, represents a departure of 0·02 from the mean curve.

Figure 6 demonstrates the maximum anomaly in the potential temperature range of 3·51° to 4·00°C. In this range the general and well known features show up clearly: the water of Labrador Sea origin occupies the most northern parts covered, and to the south of it is found the great tongue of Mediterranean water described by Helland-Hansen, Wüst, and many others. South of this lies the fresher Antarctic Intermediate Water.

Certain other features appear in the figure: notably the appearance south of Iceland of Norwegian Sea water lying between the British Isles and Rockall Bank which has overflowed the Iceland-Faroe Ridge, and a weaker intrusion of more saline water which probably overflowed the Faroe-Shetland Ridge.

Another point of interest is the Caribbean basin which is uniformly fresher than the water outside the Anegada Passage, which suggests that water is not at present flowing into the basin. In the Yucatan basin, however, there is evidence that water does flow in through the Windward Passage in small quantities.

In the equatorial region there is evidence of a strong easterly flow similar to, but somewhat deeper than, that described by Knauss in the Pacific; the bulk of these observations fall at about 1,700 m. Figure 7 illustrates the same intrusion into the relatively fresh water in the east of the slightly more saline water from the west within the temperature range of 3·01° to 3·50°C which lies at a depth of about 2,000 m.

The same general distribution of water masses is found in this temperature range as in the previous one, but the Norwegian Sea overflow is more widespread and has values as high as 0·05 ‰ on the saline side of the curve.

In Figure 8, variations from the mean θ/S curve in the temperature range between 1·76° and 2·00°C have largely disappeared from the western North Atlantic. The water north of the South-East Newfoundland Ridge shows up clearly as more saline

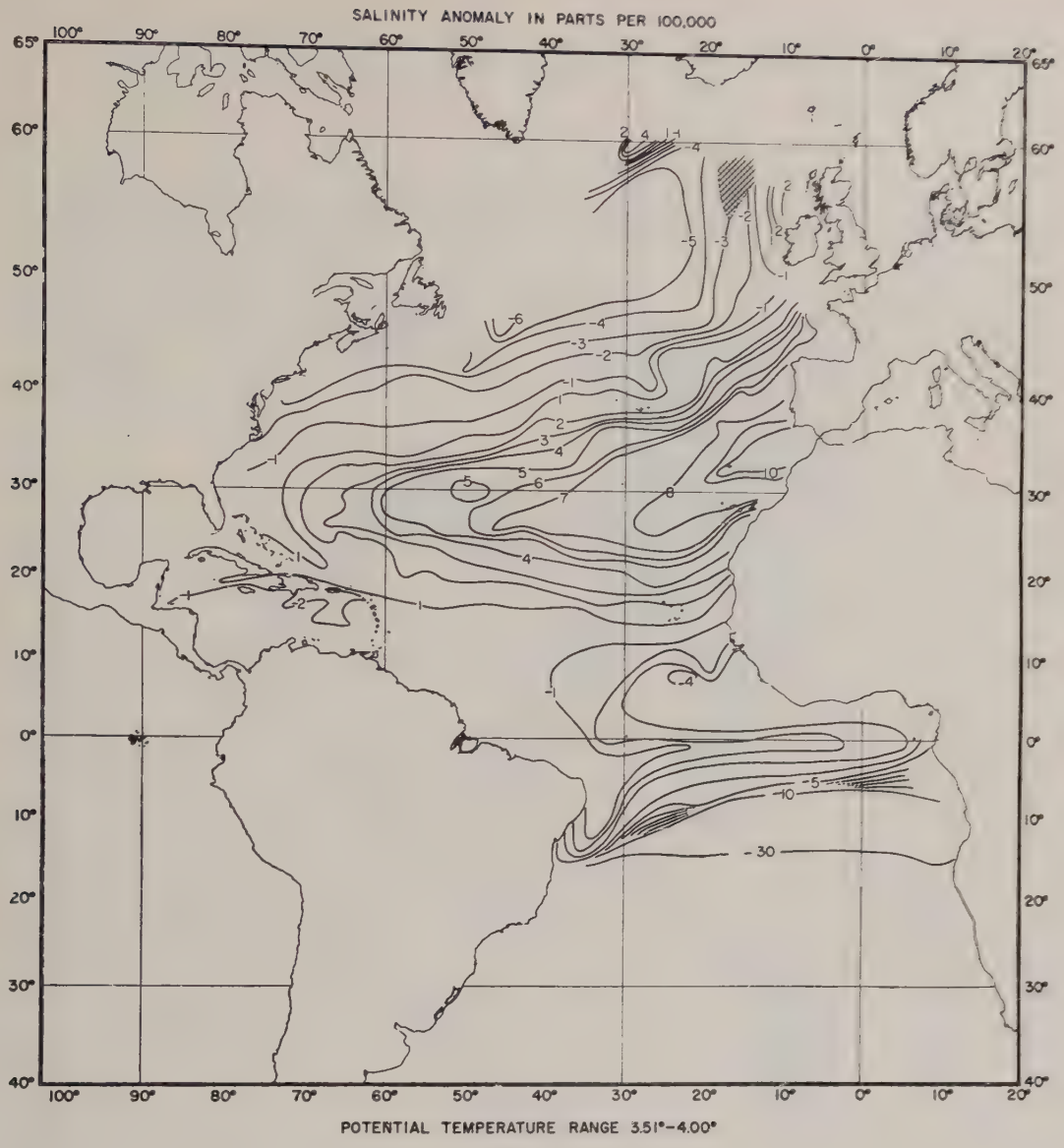

Figure 6.

ome of this escapes into the deep American basin, it most of it, especially the colder (deeper) portion, is contained by the ridge. A tongue of low nomaly water appears as a southern movement ong the western boundary of the Atlantic in this mperature range, and a corresponding flow to the orth along the western slope of the Mid-Atlantic idge reaches up into the American basin as far as °N latitude.

Figure 9 showing the observed temperatures at 500 m gives a further indication of this movement. ne outstanding feature demonstrated in this figure of course, the indication of the western basin of the South Atlantic as the source of the cold deep water found in the rest of the Atlantic Ocean. Communication between the eastern and western basins takes place across the low point in the Mid-Atlantic Ridge near the equator where the very deep Romanche Trench is found. The exact sill depth is not known, but the crowding together of the isotherms in this area in the figure indicates that it is somewhat shallower than shown here. The cold water, after spilling over into the eastern basin, spreads out both to the north and south becoming warmer as it goes.

The invasion by the cold Antarctic Deep Water

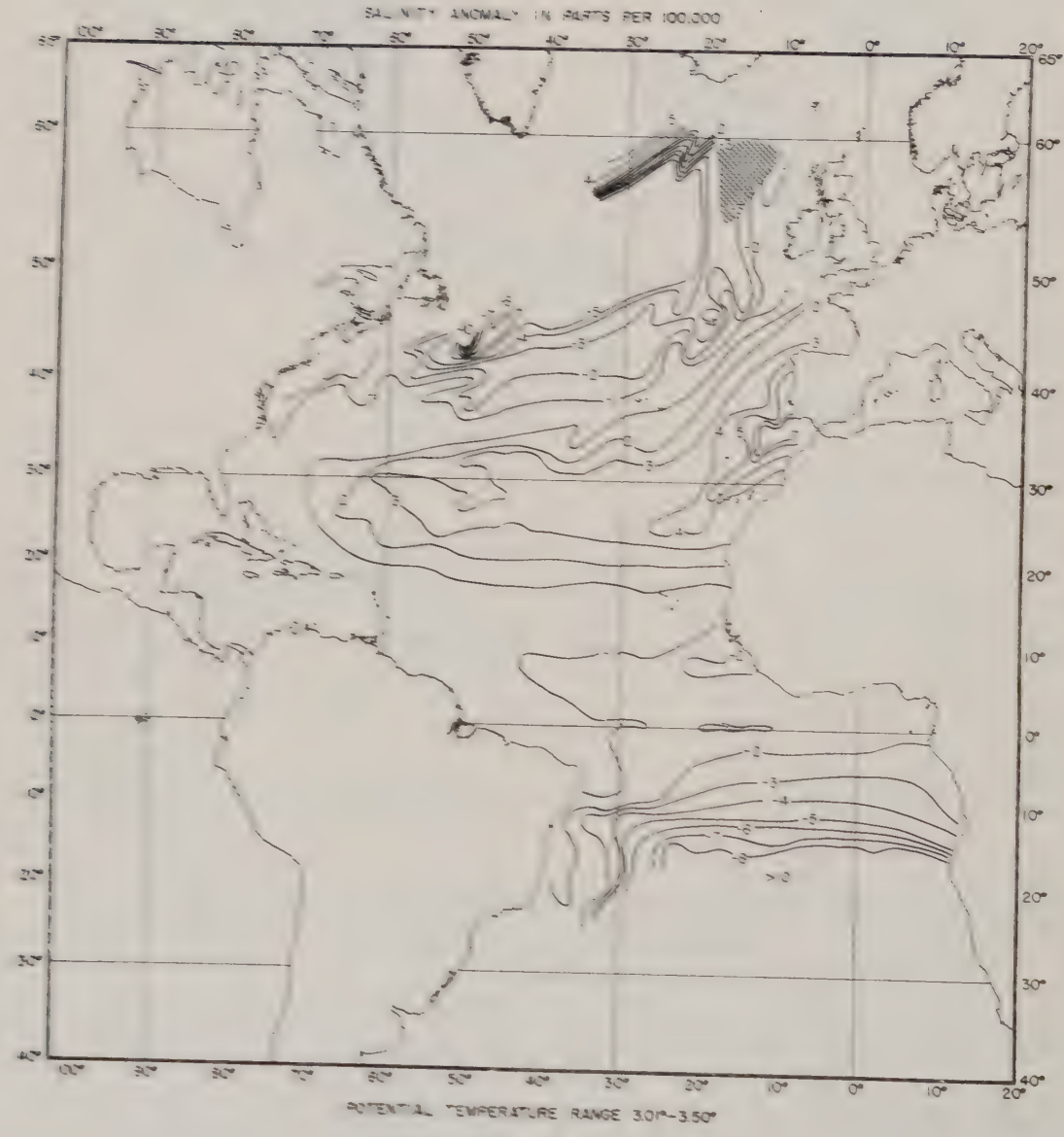
SALINITY ANOMALY IN PARTS PER 100,000
POTENTIAL TEMPERATURE RANGE 3.01°-3.50°

Figure 7

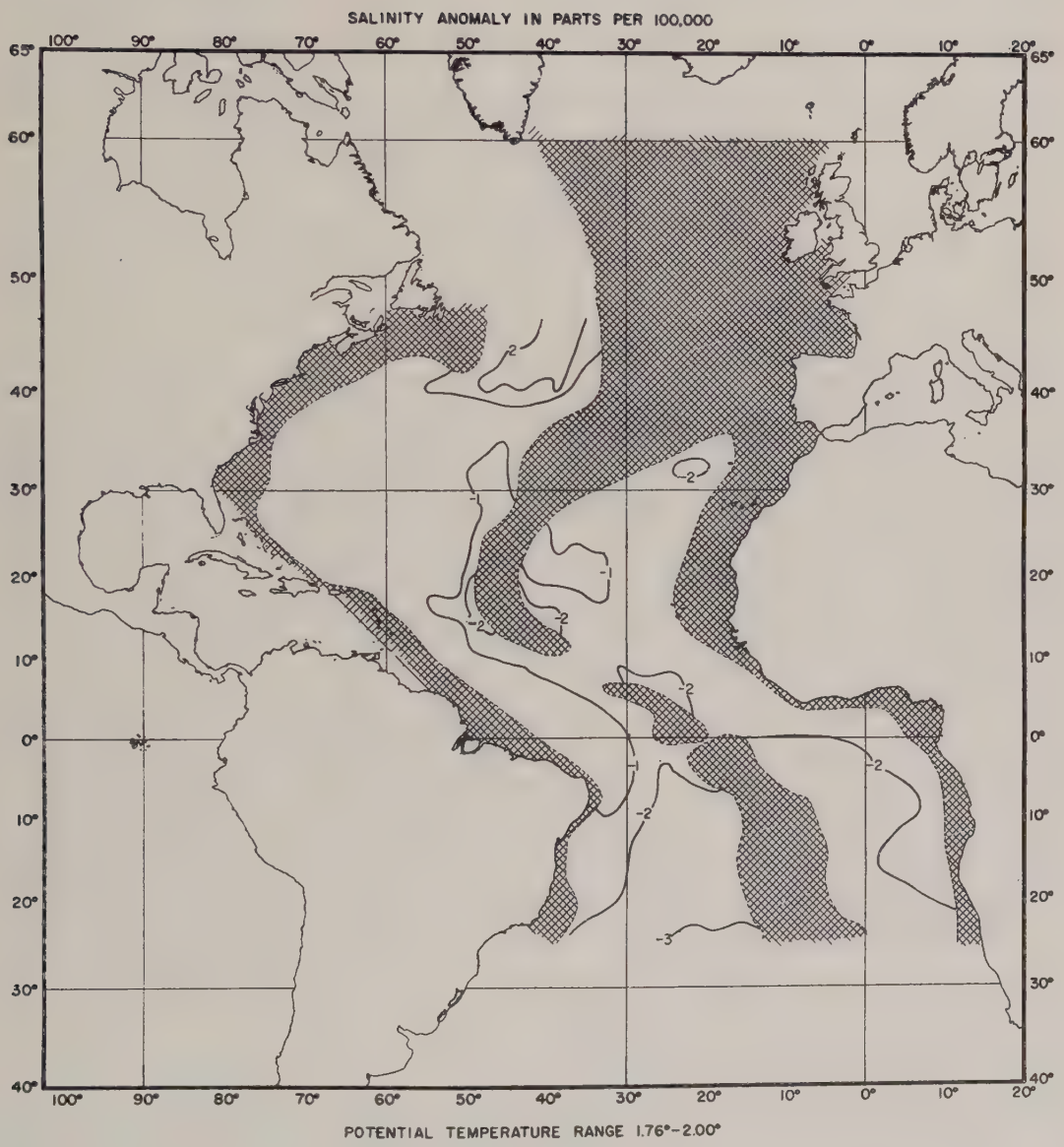
SALINITY ANOMALY IN PARTS PER 100,000
100° 90° 80° 70° 60° 50° 40° 30° 20° 10° 0° 10° 20°
65° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40°
-2
-1
-3
POTENTIAL TEMPERATURE RANGE 1.76°-2.00°

Figure 8.

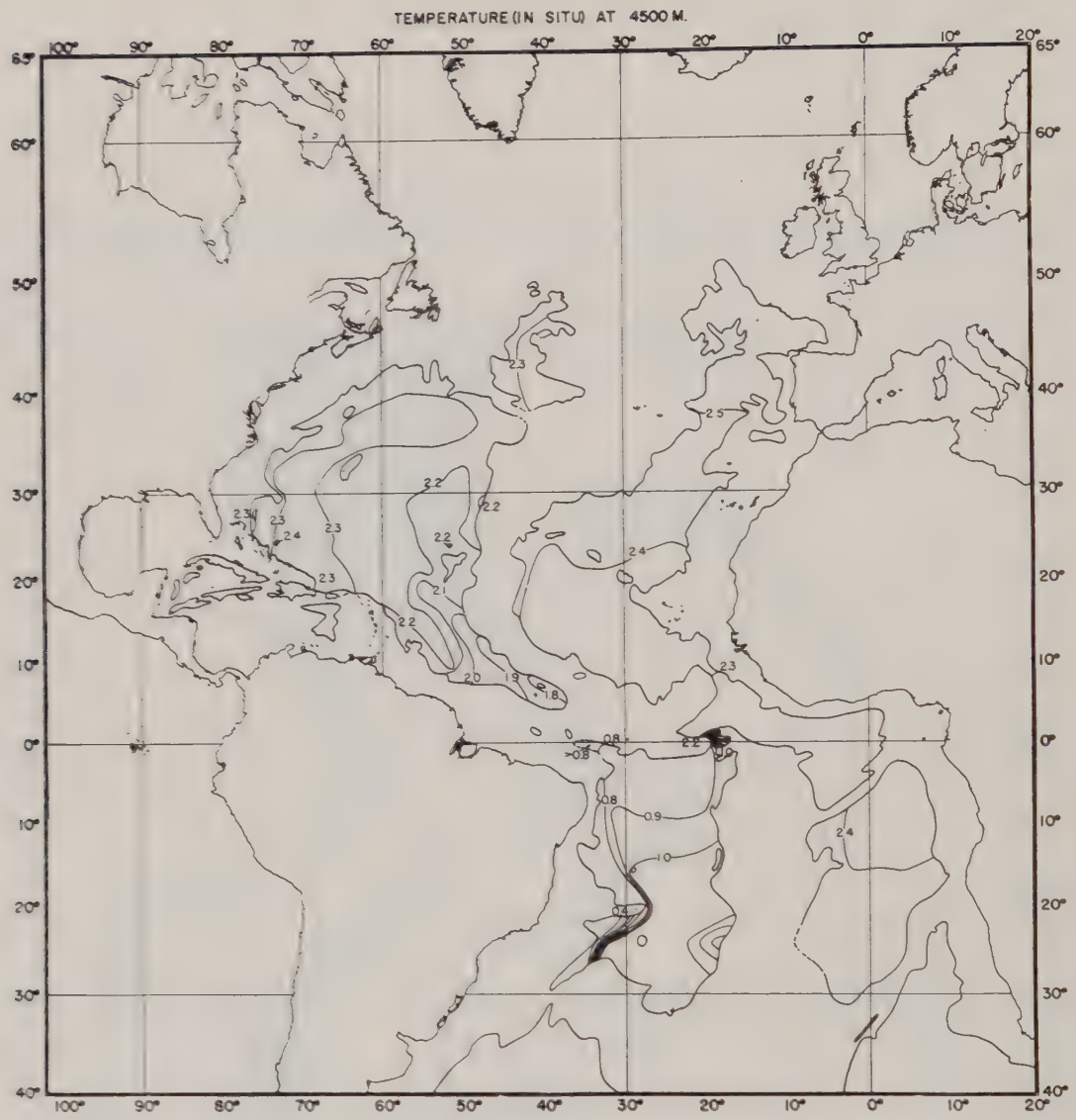

Figure 9.

into the western basin of the North Atlantic appears to take place at the narrowing of the rise just north of the equator. The cold water then works its way along the western slope of the Mid-Atlantic Ridge becoming somewhat warmer as it goes and eventually appearing as a belt of cool water lying on three sides of a slightly warmer tongue of water seen in the figure stretching from the Antilles Arc north beyond Bermuda and then to the east.

The deep basin near the southern African coast is cut off at the deeper levels from the basins to the north. It is filled with cold water of Antarctic origin and has no apparent effect on the deep wa found to the north.

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24.

Results Obtained during the IGY by the Institute of Oceanography and some Provisional Interpretations

By

R. A. Cox

National Institute of Oceanography, Wormley, England

Summary

The joint survey of the North Atlantic made by the National Institute of Oceanography and the Woods Hole Oceanographic Institution has given a new and most comprehensive set of hydrological data covering the whole ocean. The major part has been published as a WHOI internal report (1) and the later cruise will shortly be described in another similar report. The silicate and phosphate results in an east/west section at 25°N show a surprising stripping of silicate, but not of phosphate, in near-surface water.

Current measurements with the Swallow float in an area 300 miles west of Portugal gave interesting results. These are published in full in *Deep-Sea Research* (2). The results showed quite surprising variations in both time and space of the deep-sea currents. Two similar floats at about 2,600 m in water 5,300 m deep showed very different movement. One drifted steadily west at 150 m/hr, while the other, only 25 km away, remained stationary except for the tidal oscillation.

Another investigation in the area east of Gibraltar employed the Swallow floats in conjunction with conventional hydrological sections to study the outflow of Mediterranean water into the Atlantic. The main flow followed the Spanish coast at velocities near 0·5 knots. Further south another area of high salinity water was shown by the floats to be a large eddy with the water completing an elliptical movement in seven days. A summary of these results has been published by Tchernia (3), and a more complete account is in preparation by F. Fuglister and will appear shortly as a WHOI internal report.

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(1) Woods Hole Internal Rep., ref. 59–30, June 1958.

(2) Swallow, J. C., & Hamon, B. V., 1960. "Some measurements of deep currents in the Eastern North Atlantic". Deep-Sea Res., *6*: 155–68.

(3) Tchernia, P., 1959. "Compte-rendu succinct d'une campagne d'observations hydrologiques executée dans le golfe de Cadix à bord du 'Discovery II' en Novembre 1958". Cahiers océanogr., *11* (3): 148–54.

25.

Preliminary Report on Current Measurements in 1958 on the Galicia Bank West of Cape Finisterre

By

Odd H. Sælen

Geofysisk Institutt, Bergen, Norway

In the summer of 1958 the research ship "Helland Hansen" took part in a cooperative programme in the area west of Portugal. The work done by our ship is indicated in Figure 1. Stations in two sections along lines of latitude are indicated by crosses. At the location denoted by A current measurements from an anchored ship were attempted on the continental slope. The ship drifted, however, and the measurements had to be discontinued rather soon. In the area C, the "Discovery II" conducted experiments with Swallow's deep-sea float, while "Helland Hansen" made numerous hydrographic stations in the same area. The present report will be concerned only with the current measurements

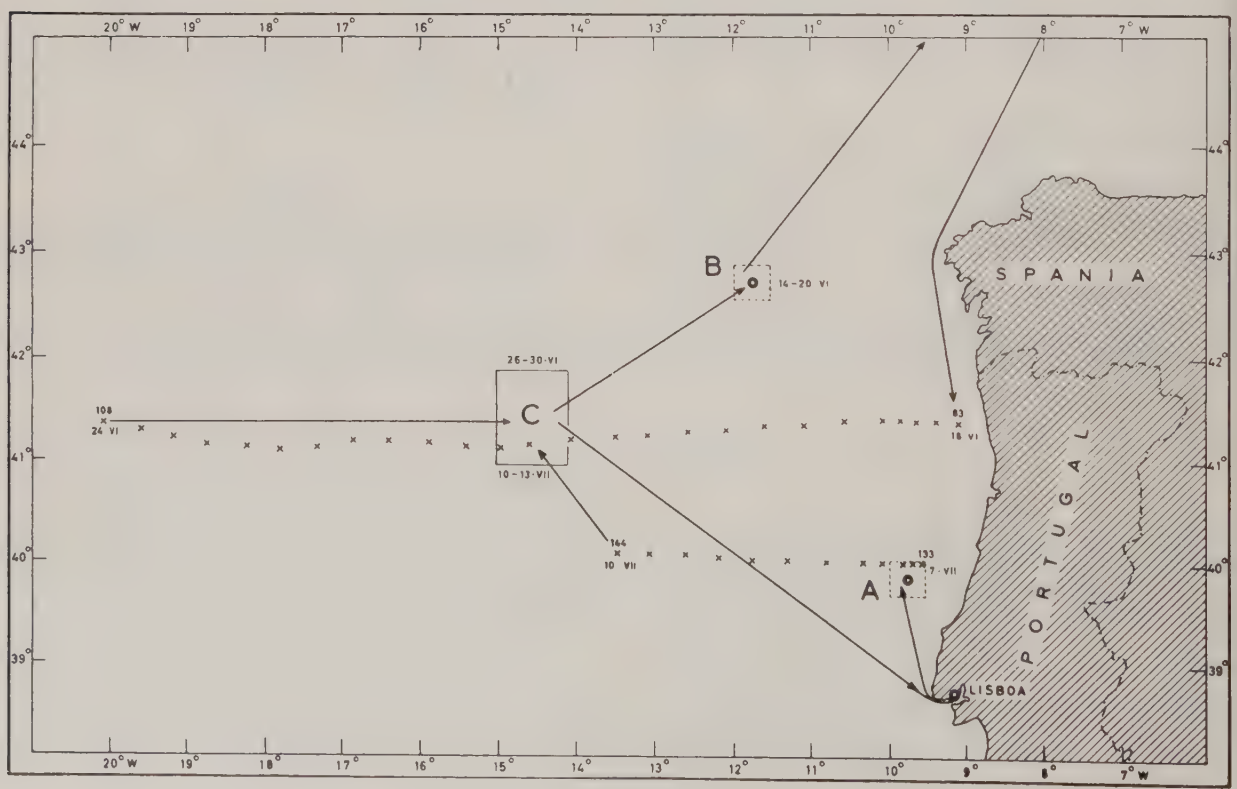


Figure 1.

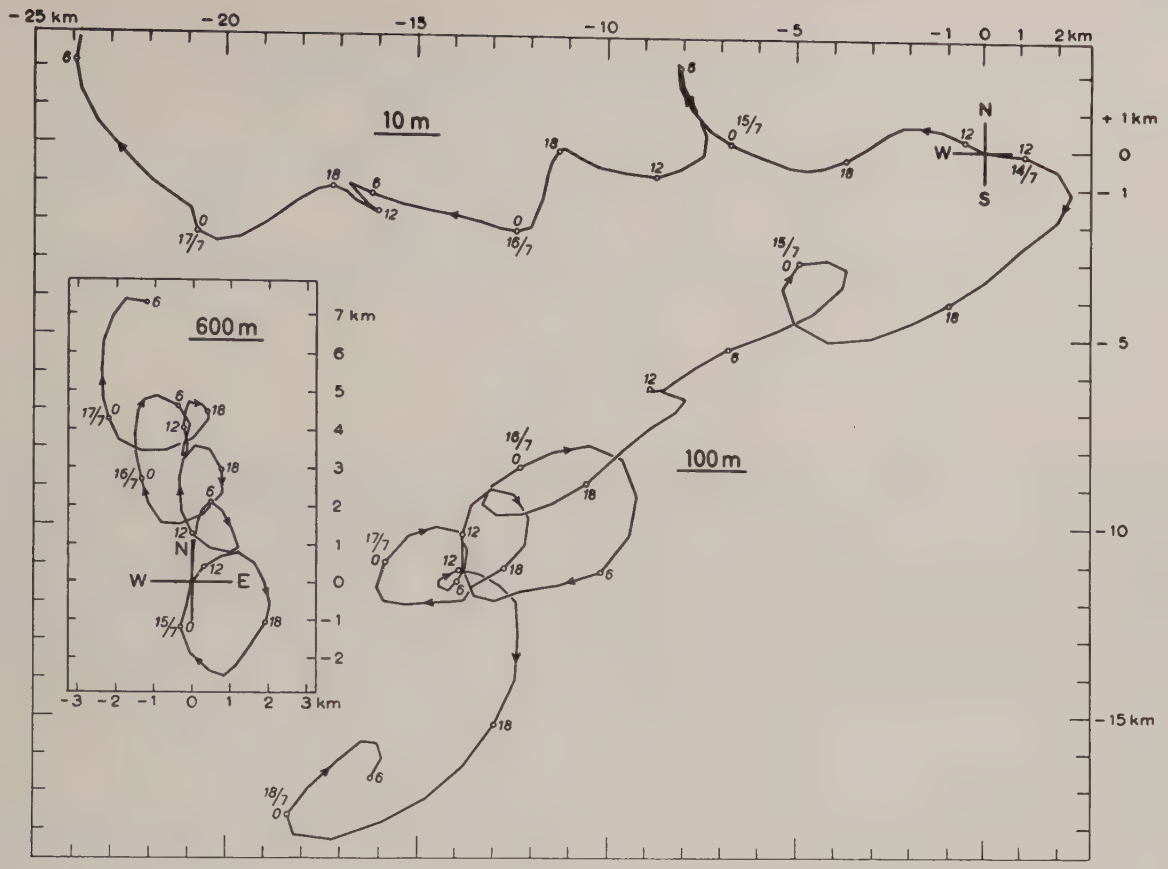


Figure 2.

made at the anchor station indicated by B in Figure . The station is located in 42°42'N, 11°47'W on he top of the Galicia Bank with a bottom depth of 760 m. The ship was anchored for nearly four days and the following series were obtained:—

With the usual Ekman current meter: a series of 69 hours at 10 m, a series of 69 hours at 25 m, a series of 90 hours at 100 m. With the Ekman repeating current meter: a series of 67 hours at 600 m. With the Sverdrup-Dahl electric current meter: a series of 42 hours at 75 m. With Mosby's bottom current meter: a series of 22 hours 1·5 m above bottom.

The weather was fine during the measurements with winds from 0—3 Beaufort.

The results given below are not to be considered he final analysis: it is a rough draft based on a preliminary inspection of the data.

In Figure 2 the results of the current measurements at the depths 10, 100, and 600 m are presented as progressive vector diagrams. The residual currents, taken roughly as the rate of total displacement during the observation period, are as follows: at 10 m of the order 10 cm/sec.; at 100 m, 6 cm/sec.; and at 600 m, 3 cm/sec. The directions also differ: at 10 m the average flow is toward west, at 100 m toward SW, and at 600 m toward NNW. In these diagrams the tidal influence is most clearly seen in the loops occurring in the curves for 100 and 600 m. There is obviously a *cum sole* rotation of the velocity vector. Because of the higher residual velocity at 10 m, such loops are not found in the curve for that depth. In Figure 3 we have therefore reproduced the N and E components (smoothed) for that depth. A period of about 12 hours is clearly seen, especially in the curve for the N component. The more irregular course of the E component may be due to the fact that the residual current, which is directed toward west, is more exposed to irregular variations than is the tidal part of the current. The tidal current at 10 m seems to be nearly alternating: there is not in any case such a clear indication of rotation as at 100 and 600 m. At 25 m (not reproduced here) conditions are much the same as at 10 m. At 75 m (not reproduced here) there seems to be an indication

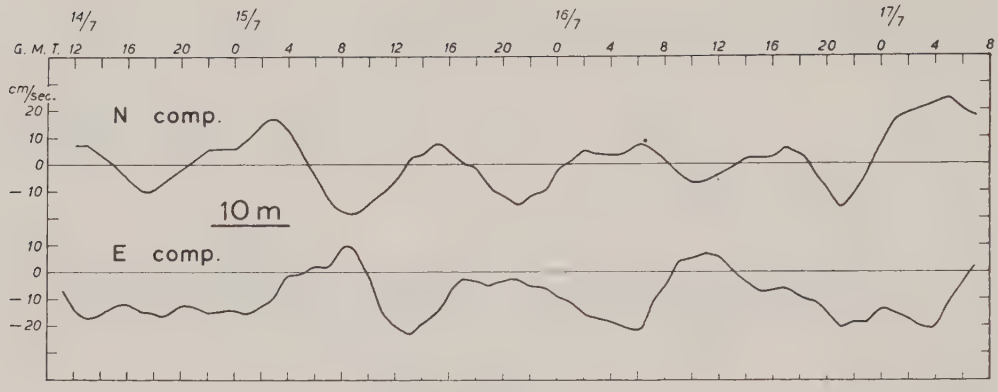


Figure 3.

that the tidal current has a rotation *contra solem*. The strength of the tidal current does not decrease with depth. In fact, it seems to be at least as strong at 100 and 600 m as at 10 m. As the residual current decreases with depth, the tidal part of the current becomes increasingly prominent with increasing depth. Thus, with a residual current of 3 cm/sec. at 600 m, the strength of the tidal current is about 20 cm/sec. This development is clearly see from Figure 2. The bottom current measuremen were not made so frequently that they can be pr sented in a diagram comparable to those in Figu 2. In one part of the series the velocity vect rotates *cum sole*, with an irregular rate, once about 12 hours, with velocities between 10 an 20 cm/sec.

26.

Distribution de la Salinité et de la Température au Méridien de Tarifa en Août 1958*)

Par

N. Menéndez

Du 7 au 23 août, Instituto Español de Oceanografía réalisa une campagne océanopraphique dans la zone du Détroit de Gibraltar, collaborant aux travaux de l'Année Géophysique Internationale avec les vaisseaux français « Winnaretta-Singer » et « Passeur du Printemps ».

Le principal but octroyé au vaisseau espagnol « Segura » fut la détermination de la structure thermohaline sur une ligne proche du Méridien de Tarifa en fonction des différentes heures de marée.

Au cours de la campagne prédominèrent des vents de l'ouest dont l'intensité moyenne était de 8 m/sec., voire plus grande.

Le dragueur de mines « Segura » n'avait pas de dispositif de mouillage et le câble du treuil hydrographique ne pouvait guère supporter des séries de bouteilles à renversement allant au-delà de quatre ou cinq. De telles circonstances défavorables empêchèrent à cause de la dérive du vaisseau que l'on puisse plonger toutes les séries de bouteilles aux cinq stations prévues sur le Méridien de Tarifa causant ainsi la dispersion des stations et des prises d'échantillons, montrées sur Figure 1.

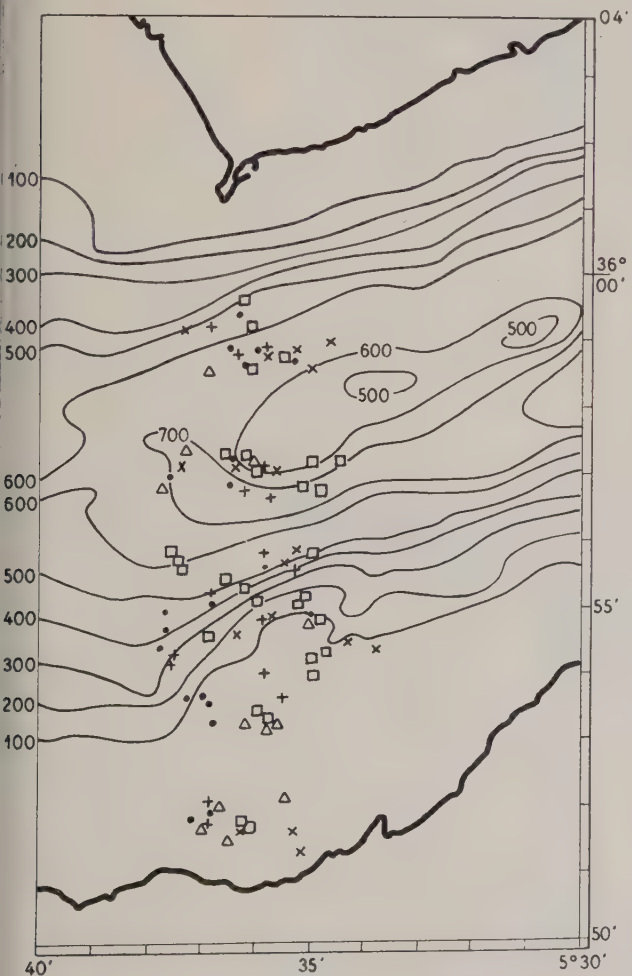


Figure 1. Disposition des stations.

*) Le texte plus approfondi du travail sera publié dans le Boletín de Instituto Español de Oceanografía à date prochaine.

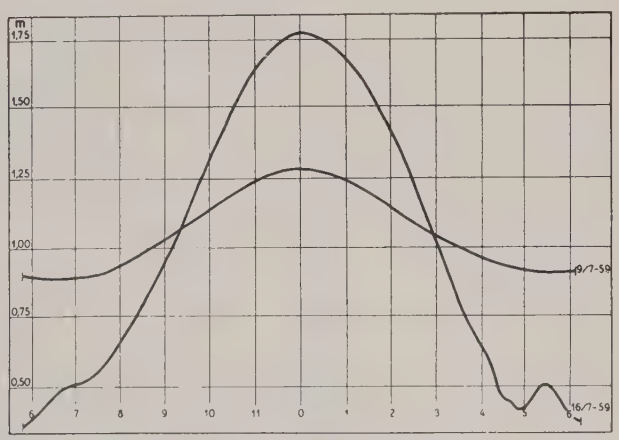


Figure 2. Valeurs maxima de la marée.

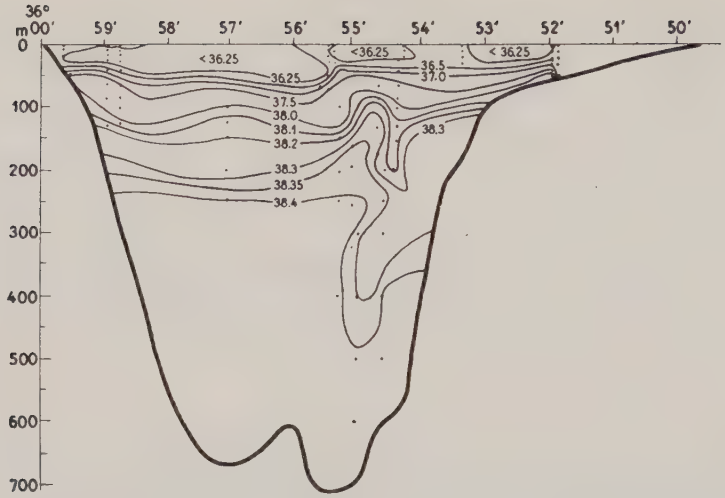


Figure 3. Pleine mer. Les isohalines.

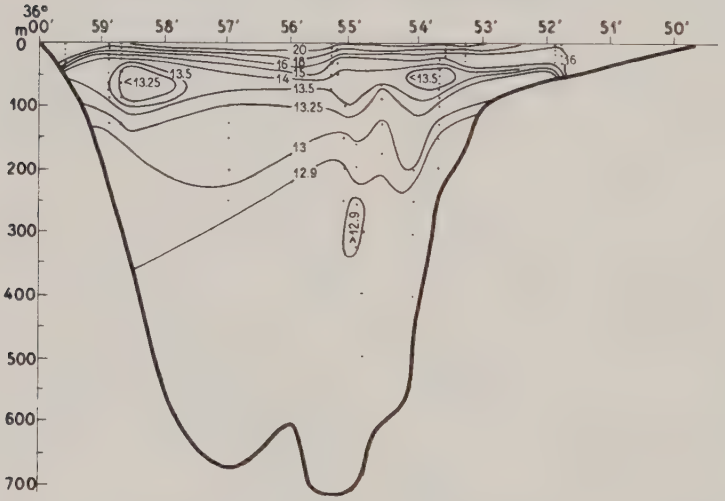


Figure 4. Pleine mer. Les isothermes.

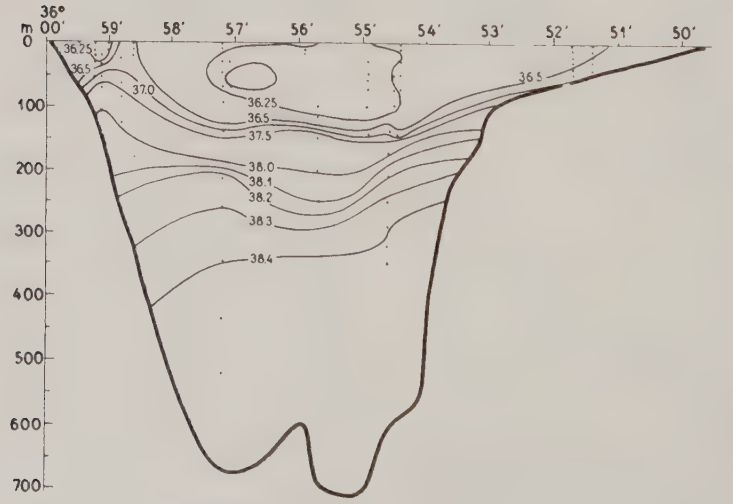


Figure 5. Reflux. Les isohalines.

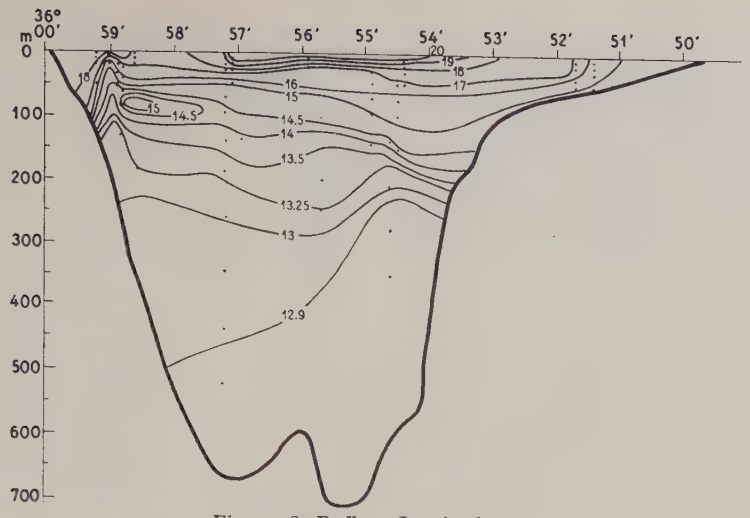


Figure 6. Reflux. Les isothermes.

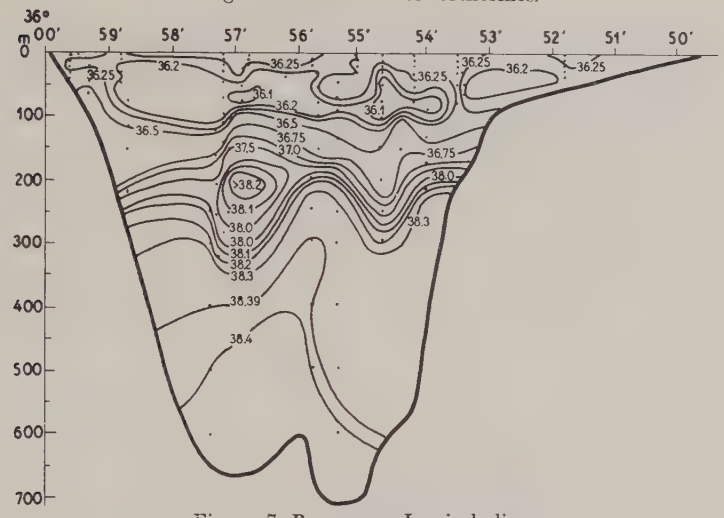


Figure 7. Basse mer. Les isohalines.

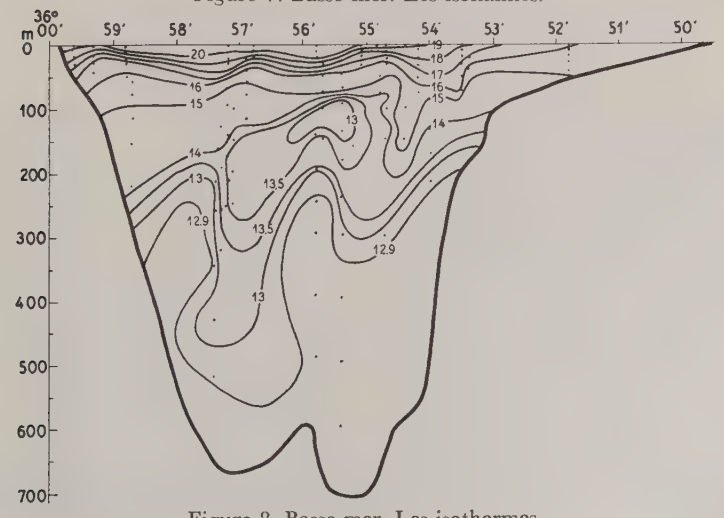


Figure 8. Basse mer. Les isothermes.

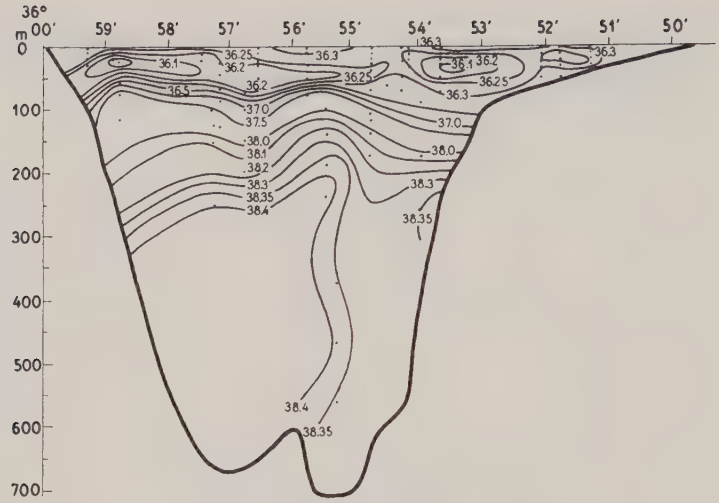


Figure 9. Flux. Les isohalines.

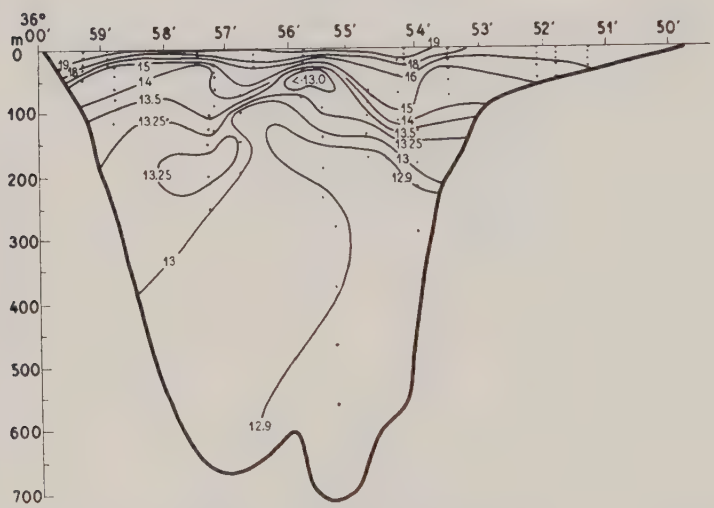


Figure 10. Flux. Les isothermes.

Pour parer à cet inconvénient et utiliser le plus possible les renseignements obtenus, nous partons de l'hypothèse de ce que, le mouvement de l'eau au Détroit étant parallèle à son axe longitudinale, il s'ensuit logiquement que les caractéristiques thermohalines doivent moins changer dans ce sens longitudinal que dans le transversal parallèle au Méridien de Tarifa, c'est-à-dire, que nous faisons une représentation des structures thermohalines situant les stations dans le profil suivant leur latitude.

Pour avoir un nombre de stations nous permettant de tracer les isohalines et isothermes aux différents états de la marée, nous prenons: comme données de pleine mer toutes celles obtenues entre 11 h. et 1 h. à partir de l'heure 0 de la pleine mer des différentes journées. Comme données du reflux celles obtenues entre 2 h. et 4 h. de la marée; comme de marée basse celles déterminées entre les heures 5 et 7, et comme données du flux celles trouvées entre les heures 8 et 10 de la marée.

L'ampleur de la marée changea beaucoup au cours de la campagne depuis sa valeur minima le jour 9 jusqu'à sa valeur maxima les jours 16 et 17, voir Figure 2. Cette inégalité demi-mensuelle a été négligée dans le but d'avoir à notre disposition une somme suffisante de renseignements.

On a constaté *a posteriori* que les renseignements obtenus à l'époque des marées vives n'altéraient pas sensiblement les structures dessinées d'après ceux obtenus dans la période des marées mortes si ce n'est à

rrégularité des isohalines de mer basse vers les
°57'N de latitude.

Les graphiques (Figs. 3—10) montrent en raccourci
s résultats obtenus. Leur interprétation paraît toute-
is difficile car il apparaît un accroissement de la sali-
té superficielle quand le courant semble devoir
écouler de l'Atlantique à la Méditerranée (isohalines
pleine mer et de reflux) et une diminution de la
linité superficielle aux heures de mer basse.

Cela démontrerait qu'en plus de l'origine de l'eau il faut tenir compte, comme facteur prépondérant, de l'influence du mélange des eaux atlantiques et méditerranées dans la bouche occidentale du Détroit. Le mélange est d'autant plus intense que la vitesse de la marée traversant le Détroit est importante.

Voilà un renseignement à retenir pour les prochaines campagnes.

27.

Hydrographic Investigations in the North Sea in May and September 1958

By

Jerzy Filarski

During the months under review a great number of temperature and salinity observations was carried out in the central section of the North Sea. The observations were made from the research vessel M/S "Birkut" belonging to the Sea Fisheries Institute at Gdynia. The region investigated covered:—

In May: The area 56°00'—57°30'N, 1°50'W—5°00'E, thus including the fishing grounds of the Great Fisher Bank, the Gut, the Long Forties, and the Devil's Hole. Over this area 111 stations were worked, distributed along the meridians and parallels with one station per 15 nautical miles.

In September: The area 54°00'—56°00'N, 1°00'W—4°30'E. The stations were spaced in a network comprising 49 stations at a distance of 30 naut. miles from each other.

The temperature measurements were made with Negretti-Zambra reversing thermometers fastened to Nansen water bottles. The salinity was determined partly by measurements of conductivity, partly by the Knudsen method.

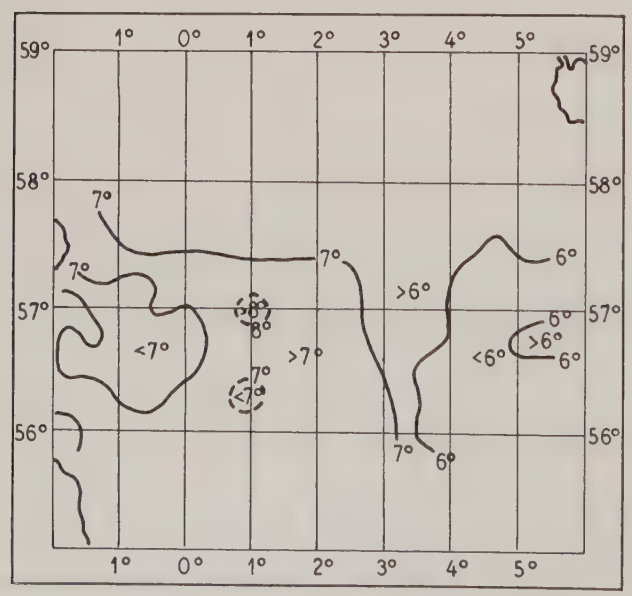


Figure 1. Surface temperatures May 1958. M/S "Birkut".

Temperature

Spring: In May the surface temperature in t eastern section of the area surveyed was som what above 5°C with the exception of a few (stations along the meridian of 5°E, where it exceed 6°C. In the central part of the area temperatur up to 6°C and even 7° were recorded.

Farther westward, towards the coasts, the temper tures again decreased. However, the coastal wate of Scotland had temperatures between 7 and 8°

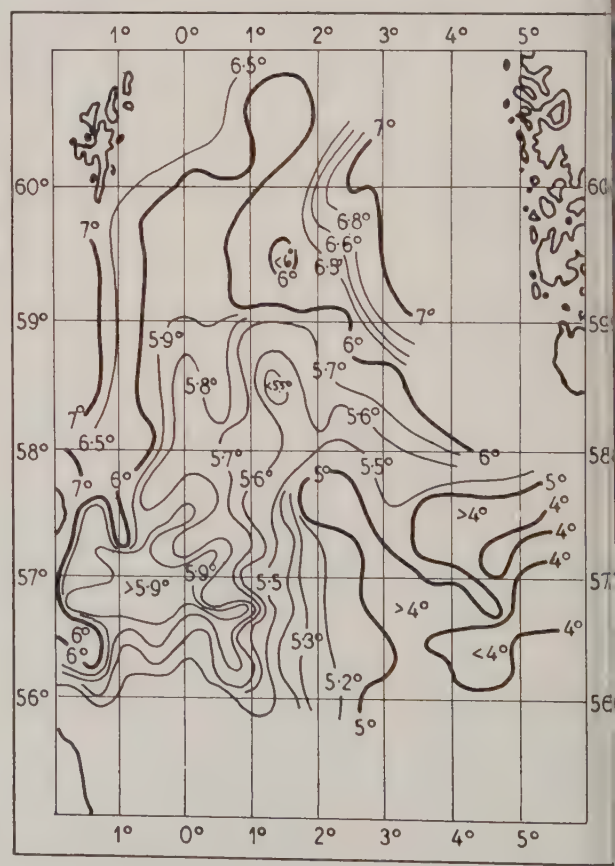


Figure 2. Bottom temperatures May–June 1958.
M/S "Birkut" south of 58°00'N.
M/S "K. Liebknecht" north of 58°00'N.

n the central part of the area investigated the ighest surface values found were 8·16°C and ·95°C.

The bottom water temperature in a section across ne central part of the area ranged from 3°C in the ast to 6°C in the west. In the eastern part, between °E and 5°E, in waters with a bottom temperature bove 4°C some water cores with temperatures of °C and 5°C were apparent.

Towards the west the temperature gradually ncreased to 5°C and even to 6°C at the Scottish oasts.

In the area situated to the north of 57°30'N he bottom temperature of the water masses was elow 6°C. Apart from this two different water ores were distinguished, the temperature of which vas below 5·7°C: the temperature minima here vere 5·35°C and 5·37°C.

Autumn: During September the surface tempera- ure over the Dogger Bank and over the fishing rounds to the north of the bank ranged between 4° and 16°C. The isotherm of 14°C was running long the Scottish coasts and in the central part f the area surface temperatures were 16°C. A teady increase in temperature from north to south vas apparent in the bottom waters in accordance vith the shape of the sea-bed of this area.

The highest temperature of the bottom water mounted to 16·3°C.

Salinity

During the spring, as in the autumn, the salinity anged between 34 ‰ and 35 ‰ all over the area nvestigated and in no cases were deviations of any nagnitude from the long-term mean for this area bserved.

Conclusions

The data collected in 1958 have been compared vith those from 1956 and 1957 as well as with the ong-term mean values for the temperature of the ottom waters.

This comparison allows the following statement o be made:—

In spring the surface temperatures were somewhat ower than in the same season of 1956 and 1957. The differences for the eastern part of the area urveyed amounted to about 1·5°—2°C and for the entral part to about 1°C. The temperatures of the oastal waters were apparently about 1°—2°C lower han for the previous years.

The bottom temperatures were also lower than he long-term means, the greatest differences being ncountered in the eastern part. Over the Fladen Ground the mean temperature of the bottom waters

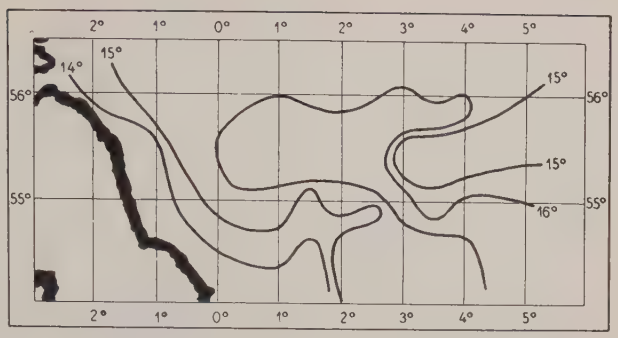


Figure 3. Surface temperatures Sept./Oct. 1958. Dogger Bank.

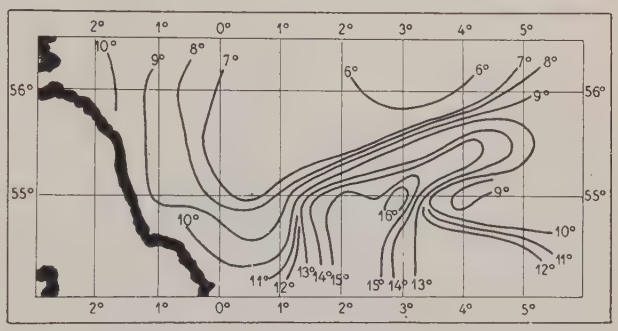


Figure 4. Bottom temperatures Sept./Oct. 1958. Dogger Bank.

at more than 10 stations deviated from the long-term mean by —0·75°C (Prahm, Ann. Biol., *13*: 78).

The unusually low bottom temperatures obviously resulted from the exceptionally long winter season and the retarded spring, when owing to the convection currents the heat of the bottom waters had been carried away.

The measurements in autumn in the Dogger Bank area show that the temperature of the surface waters was on the average higher than usually recorded and nearly corresponded to the August temperatures of the previous years, for the isotherms of 15° and 16°C in September ordinarily do not extend so far to the north. The temperatures of the bottom waters were also higher by about 1°C than the long-term mean. To the north of the bank, however, the sea-bed falls, and in accordance with this the waters showed a temperature which differed only slightly from the long-term mean.

This kind of temperature deviation (i. e., negative in the spring and slightly positive in the autumn, as compared with the long-term mean), being conspicuous both in the surface and bottom waters, must be considered the result of a strong continental influence upon the hydrographical conditions in the part of the North Sea investigated during 1958. As a consequence of these changes others concerning the biology and fishery conditions may have occurred.

28.

Temperature and Salinity Conditions in the Southern Baltic during the Period 1957 to 1959

By

A. Głowińska and B. Wojnicz

This report has been worked up on the basis of material collected by the Sea Fisheries Institute and the State Institute for Hydrology and Meteorology at Gdynia. It includes an account of the hydrographical stations, tables[1]) of the observation results, and some diagrams representing temperature and salinity conditions in the two most important areas, i. e., Bornholm Deep and Gdańsk Deep. The diagrams, of course, represent the conditions on more or less broad lines, depending as they are on observations made at irregular intervals, but they may help to give a general view of the temperature and salinity distribution in the southern parts of the Baltic during the period in question.

Figures 1 and 2 refer to temperature conditions in Bornholm and Gdańsk Deeps, respectively. They show great deviations for the year 1958 from the preceding year and the following one. The winters of 1957 and 1959 were quite mild, the lowest temperatures in the uppermost water layer in Bornholm Deep being between 2° and 3°C and in Gdańsk Deep about 2°C. The winter of 1958 was severe and temperatures of less than 1°C and somewhat above that temperature were observed in the basins mentioned. The characteristic feature of the climatic conditions during the winter of 1958 was the strong continental influence which was more prominent in the western part of the Baltic than in the south-eastern area (Gdańsk Deep). The summer of 1957 was relatively warm, the surface temperatures reaching values of above 17°C. The highest summer temperatures of 1958, however, were lower: in Bornholm Deep it was somewhat below 15°C, in Gdańsk Deep it amounted to almost 17°C, but the depth of the water layer with those values was not so great as in 1957 because of the long winter and the retarded spring.

In 1957 the "winter water" with temperatures of 2°—3°C in Bornholm Deep persisted until May while in 1958 it probably did not disappear until October; the conditions in Gdańsk Deep were almost similar. In 1959 the "winter water" in the two regions disappeared completely as early as April.

The bottom water temperature in Bornholm Deep stayed at about 5·5°C for almost all the time reported upon, except for January 1959 and following months when it rose to 7°C and afterwards fell to below 4°C. Recently (June 1959) a rise in temperature, though insignificant, has been observed.

During the period reported upon, the bottom temperature in Gdańsk Deep ranged between 4° and 5°C, except in the first half of 1957 and the spring of 1959. Recently values of over 5°C have been encountered, in February they exceeded 6°C.

Such steep changes in the temperature of the bottom waters as those in the spring of 1959 are undoubtedly caused by a salt-water inflow, which, however, seems to have been of comparatively small significance both as regards the mass of water and its salt content.

Figures 3 and 4 represent the salinity oscillations in the two deeps under consideration. After the last great inflow of salt oceanic waters into the Baltic in 1951/52 the salinity values steadily fell till the end of 1958, when the bottom salinity in the deeps probably reached the lowest values ever recorded. Thus, in Bornholm Deep the value of 14·16 ‰ on 22. November 1958 and in Gdańsk Deep the value of 10·39 ‰ on 13. January 1959 seem to be the absolute salinity minima for the period from 1902 to May 1959.

At the beginning of 1959 a small increase in the salinity values at the bottom of the deepest areas

[1]) The tables are on file in the Service Hydrographique of ICES.

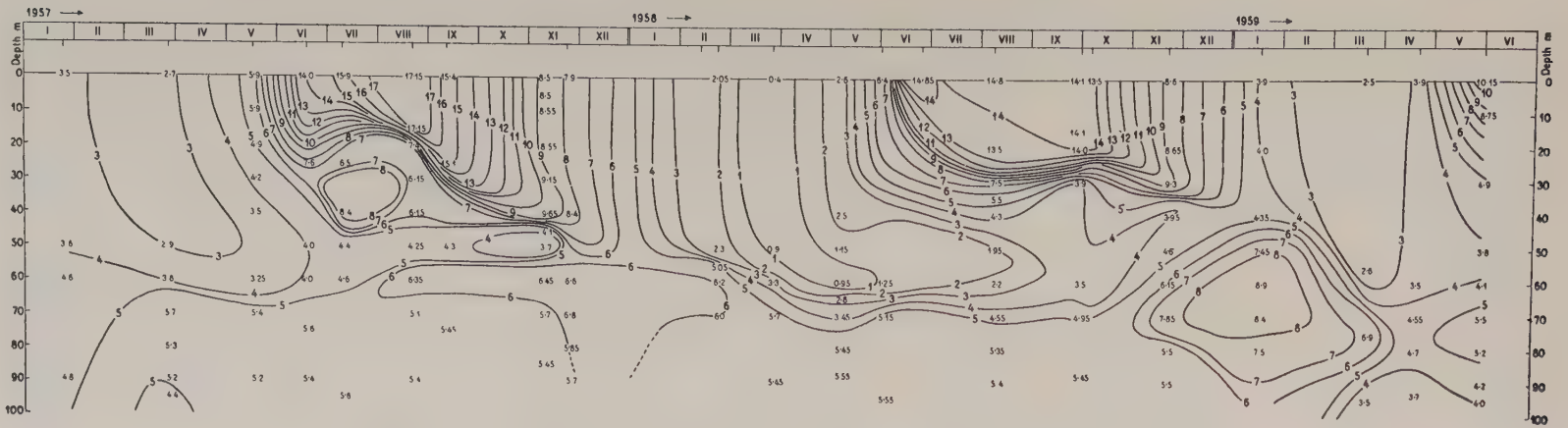

1957
1958
1959
I II III IV V VI VII VIII IX X XI XII I II III IV V VI VII VIII IX X XI XII I II III IV V VI
Depth m
0 10 20 30 40 50 60 70 80 90 100

Figure 1. Bornholm Deep. Temperature development for the years 1957–1958–1959.

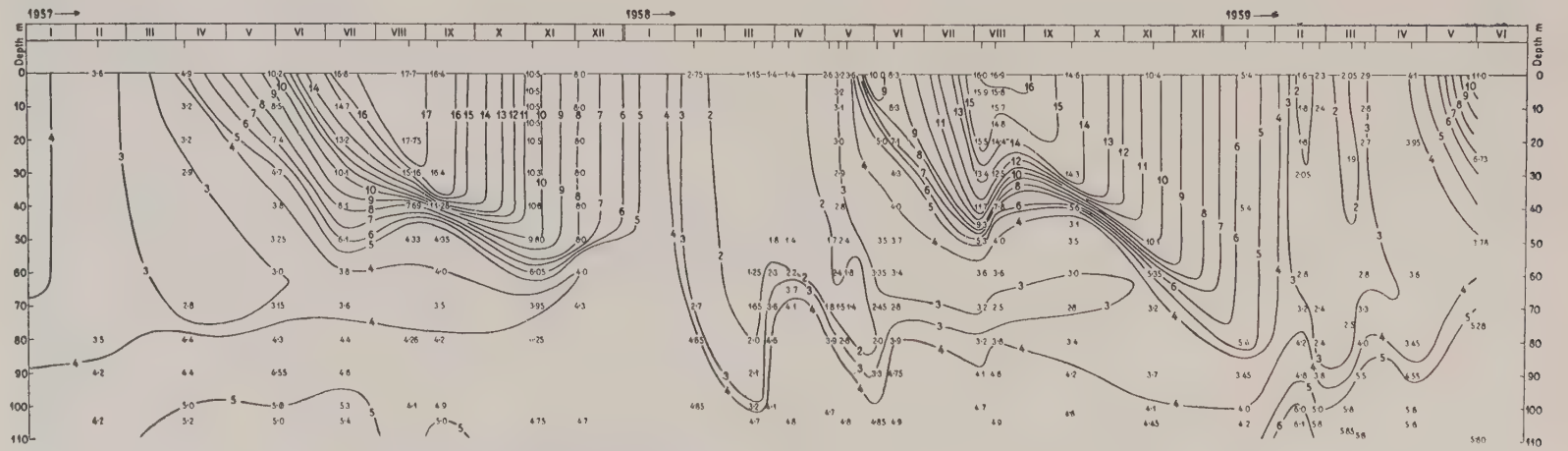

1957
1958
1959
I II III IV V VI VII VIII IX X XI XII I II III IV V VI VII VIII IX X XI XII I II III IV V VI
Depth m
0 10 20 30 40 50 60 70 80 90 100 110

Figure 2. Gdańsk Deep. Temperature development for the years 1957–1958–1959.

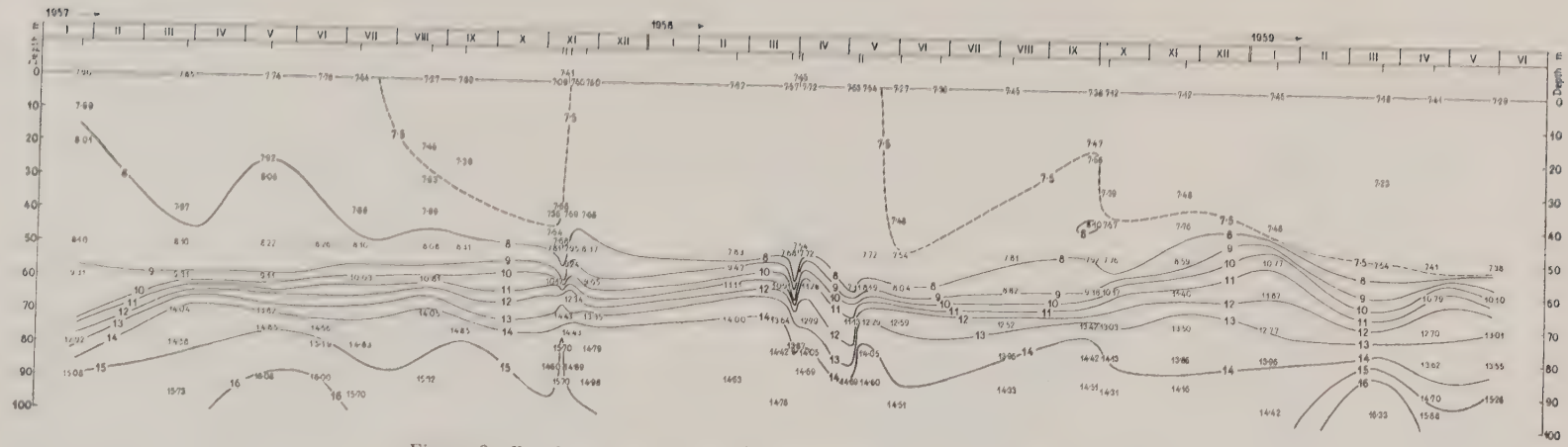


Figure 3. Bornholm Deep. Salinity oscillations for the years 1957–1958–1959.

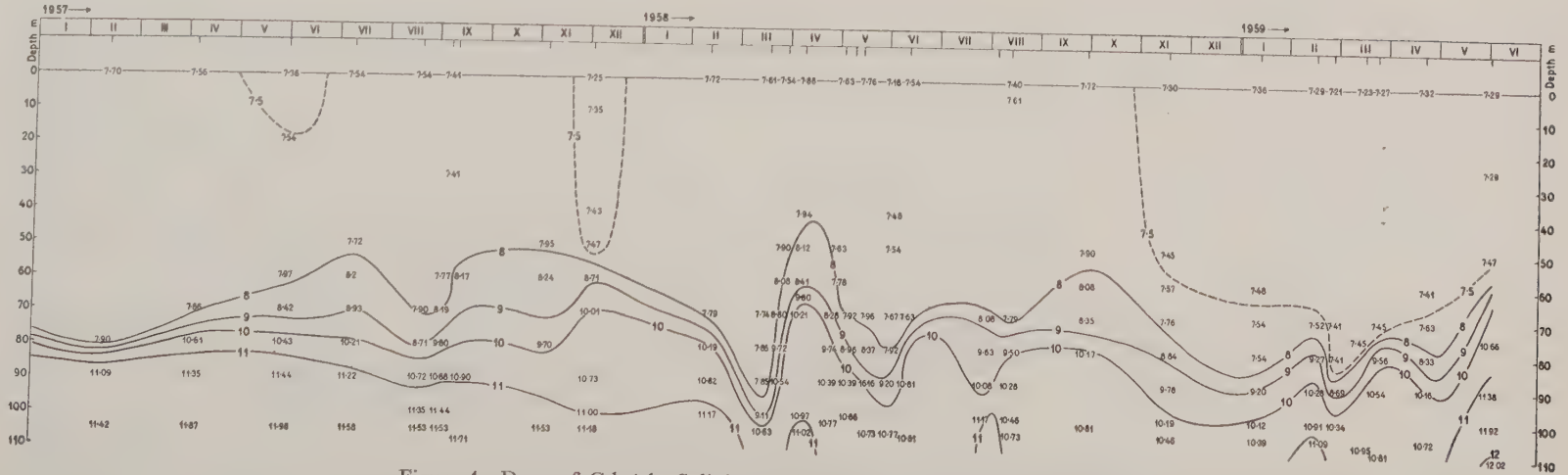
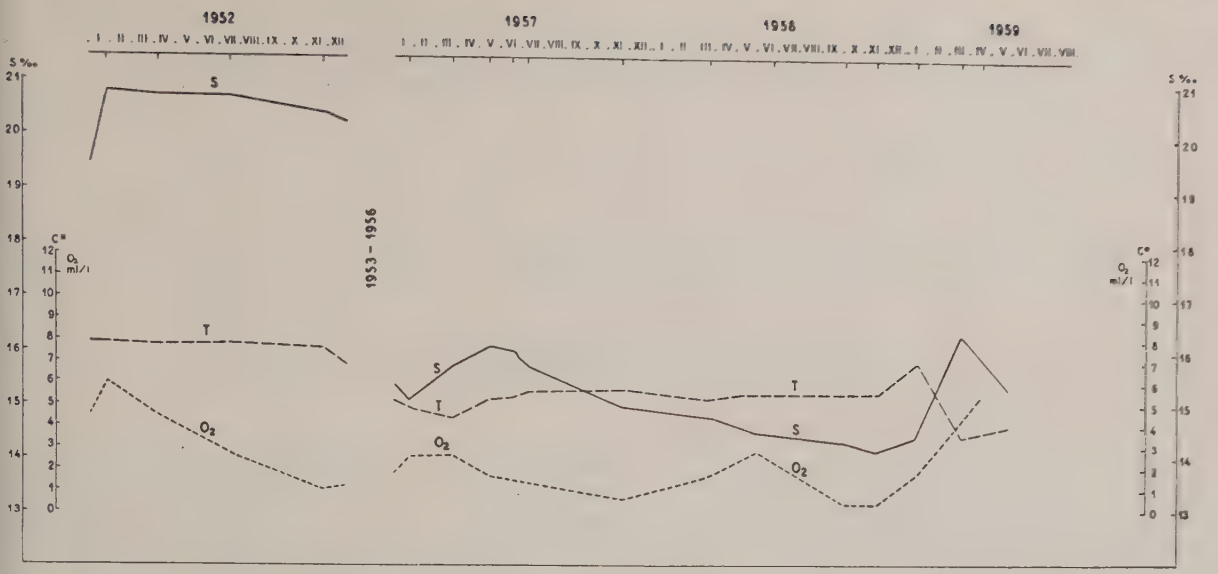


Figure 4. Deep of Gdańsk. Salinity oscillations for the years 1957–1958–1959.



Bornholm Deep
Station B_1
55°20′ N
15°45′ E

Figure 5. Temperature, salinity and oxygen content of the bottom water. Period 1957–1958 compared with 1952.

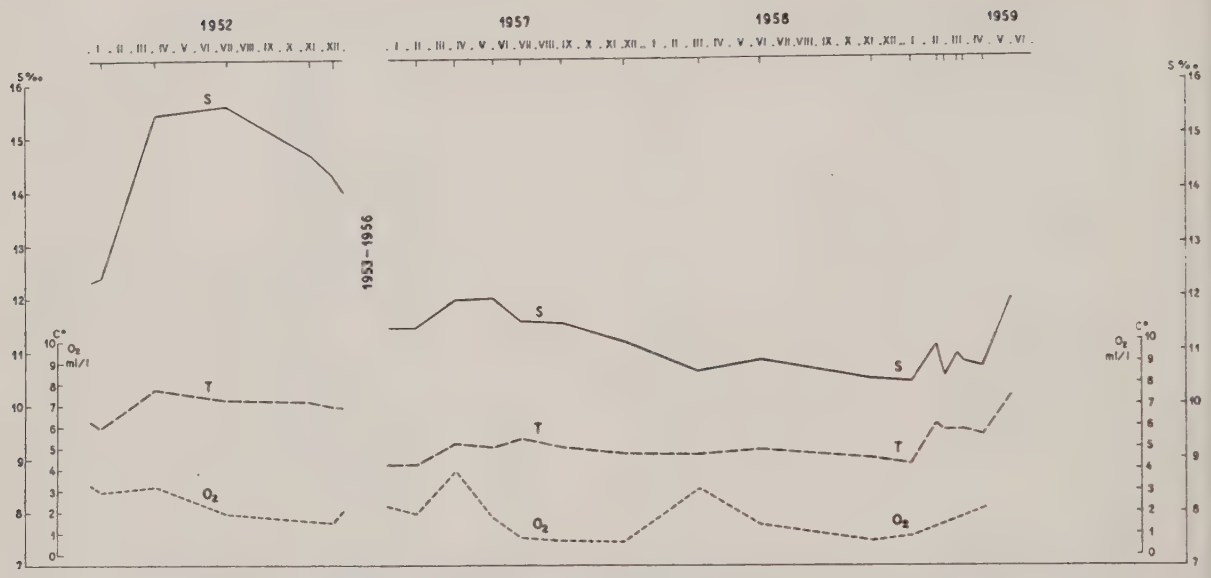
as observed. In Bornholm Deep a salinity of 6·33 ‰ was recorded at 95 m depth on 20. March nd in Gdańsk Deep a salinity of 11·09 ‰ at 05 m on 17. February. During the following months, owever, the salinity dropped again, but in Gdańsk eep it rose again to 12·02 ‰ on 1. April, i. e., a value which may be said to be rather normal r that area. The bottom salinity in Bornholm eep on 31. May was somewhat higher than 5 ‰. As regards the salinity increase which occurd in the spring of 1959 it must be considered a sult of the above-mentioned inflow of oceanic ater into the Bornholm Deep.

Figure 5 shows that in April 1959 the oxygen ntent of the bottom water in Bornholm Deep was s high as it used to be just after an inflow of ew salt waters into this deep. Comparison with at part of Figure 5 which refers to the year 952 shows that the oxygen content was to a large xtent similar for the two years, and the value of ·5 ml/l thus confirms that such an inflow has ally taken place.

During the period considered the salinity of the pper water layer decreased from a value of above ·5 ‰ to a value of below 7·5 ‰ (Figs. 3 and 4). he decrease in salinity to below 7·5 ‰ in Bornolm Deep set in about June 1958 and in Gdańsk eep about November 1958. This decrease in salinity f the upper water layers which occurred all over ie southern Baltic was undoubtedly the result of the general dilution process which had taken place in the long interval since the inflow of 1952. It may be remarked here, however, that during the previous years such cases of salinity decrease did occur, but for a short time only, as for instance in the autumn of 1957 and in May 1958. As regards the Bornholm Deep these cases may be explained as due to a temporary south-westerly spreading of highly diluted surface waters from the inner part of the Baltic along the south-eastern Swedish coast when particular wind conditions exist. The surface salinity decrease in the area of Gdańsk Deep is often the result of Vistula floods.

The thickness of particular water layers in both deeps is apparent in Figures 3 and 4.

Bornholm Deep: During the first half of 1957 the 8 ‰ isohaline was running very irregularly as opposed to those of higher value. This fact, together with the relatively high surface salinity at the same time, allows us to incorporate the waters with a salinity ranging between 8 ‰ and 9 ‰ into the upper water layer, so that the lower limit of this layer could be set along the 9 ‰ isohaline. The waters with salinity ranging between 9 ‰ and 12 ‰ (sometimes even 13 ‰) may be considered the intermediate water layer (Fig. 3). Since the second half of 1957 the 8 ‰ isohaline has to be taken as the upper limit of the intermediate layer. The bottom water layer consists of the waters with salinity above 13 ‰. If the different water layers are so



Gdańsk Deep
Station B_2
54° 50′ N
19° 16′ E

Figure 6. Temperature, salinity and oxygen content of the bottom water. Period 1957–1958 compared with 1952.

defined, the thickness of the top layer oscillated from 40 to 60 metres; that of the intermediate layer between 10 and 30 m; the upper limit of the bottom water layer was situated at 60 to 70 m depth when defined as the isohaline of 12 ‰.

Gdańsk Deep: In comparison with Bornholm Deep the isohalines in Gdańsk Deep showed much greater oscillations. The thickness of the top layer limited at its bottom by the 8 ‰ isohaline during the period reported upon was changing from about 55 m to about 95 m. The following isohalines composing the intermediate layer (8 ‰, 9 ‰, 10 ‰, and perhaps 11 ‰) were running more or less parallel to each other. At the beginning of 1957 the thickness of the layer was less than 10 m; sometimes, however, as for instance in the autumn of 1958 or in Apri 1958 (this last time taking the 10 ‰ isohaline a the lower limit) the intermediate layer had a thick ness of 25 m to 30 m. In general, the waters wit salinity above 10 ‰ is here considered as constitu ing the bottom water layer. The upper limit for th years reported upon oscillated from 64 m dept (April 1958) to 103 m depth (18. March 1958 The isohaline 11 ‰ which was present during 195 disappeared probably at the beginning of 1958 bu is apparent once more at about the end of Ma 1959, this time together with the isohaline of 12 ‰ so that in the last part of the period reported upo a return to the normal salinity conditions in Gdańs Deep has taken place.

29.

Ice Research in the Baltic Sea during the International Geophysical Year

By

V. V. Betin and Y. V. Preobrazhensky

State Oceanographical Institute, Leningrad Department, Leningrad

The possibility of maintaining winter commercial traffic and fishing in the Baltic Sea not only depends on, but in many instances is directly determined by ice conditions. It is therefore natural that special emphasis was laid on ice research during the International Geophysical Year. As early as in 1952/1954 a special Joint Committee set up at the Leningrad branch of the State Oceanographical Institute completed work on a comprehensive "Classification and Terminology of Sea Ice" a considerable part of which was incorporated in the "Concise International Ice Nomenclature". In later years a number of manuals on aerial ice observations were prepared and published, e. g., new "Directions for Ice Observations at Coastal Stations and Posts" (1956), an "Album of Sea Ice Formation" as well as other manuals designed to secure uniform coastal and ship ice observations. From the beginning of the International Geophysical Year a special large-scale programme of ice observations went into operation at coastal hydrometeorological stations and posts, as well as on ships navigating in ice. Special attention was devoted to conducting aerial ice observations.

As distinct from other observational facilities, aircraft make it possible to photograph within a short period of time an almost instantaneous picture of the condition and distribution of ice throughout any particular sea area or even the sea as a whole, including those areas which, for one reason or another, are inaccessible for ship or coastal observations. Unfortunately, the opportunities offered by modern aviation could not be fully utilized due to the lack of instrumental methods for aerial ice observation. It was for this reason that a quasi-instrumental method of aerial sea ice observation was developed by USSR which permitted ice distribution maps to be compiled with an accuracy (relative error) of 3—5 %. All aerial ice observations in the Baltic Sea during the International Geophysical Year were made by means of the quasi-instrumental method with the help of aerial photography.

The winter of 1957/58 in the Baltic Sea was characterized by well-defined natural synoptical periods during which a definite trend in the course of the principal hydrometeorological factors, which control the course of the ice processes in the sea, was observed.

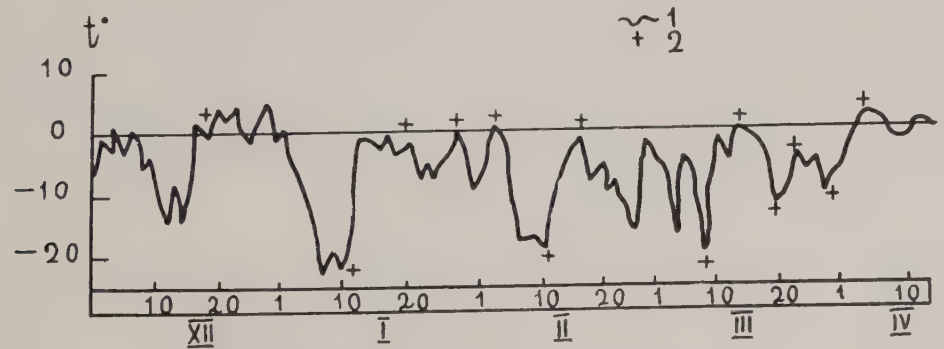


Figure 1. The course of air temperature and the time of aerial ice surveys in the winter of 1957/58.
1 = the course of air temperature in Leningrad;
2 = the time of aerial ice photographing in the Baltic sea.

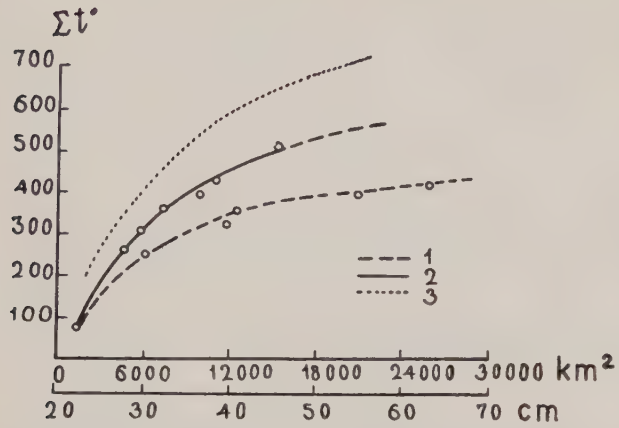


Figure 2. The relationship between accumulated temperature and ice extension area in the Gulf of Finland.
1 = relation between accumulated temperature and ice extension area;
2 = relation between accumulated temperature and immobile ice extension area;
3 = relation between accumulated temperature and ice thickness accretion.

In conformity with these synoptical periods a quasi-instrumental aerial photography of the ice situation in the sea was carried out (Fig. 1). It should be noted that the photographing of ice was timed to take place at the end of one natural period (or at the beginning of the next). In this way the photographs represented the resultant effect of a particular course of hydrometeorological factors on the extension and distribution of ice over the sea, rather than some intermediate ice situation in the sea which developed in the course of the synoptical period. It was for this reason that the ice photography material proved to be easily comparable with the course of the meteorological conditions during the winter.

The material obtained by quasi-instrumental aerial photography during the period of the development of ice in the Gulf of Finland (i. e., from the beginning of ice formation till the first spreading of ice over the whole water area of the gulf) was compared with the course of the accumulated temperature in Leningrad calculated as from the formation of immobile ice in the Leningrad Trading Port. The relation between the accumulated temperature and the ice extension area in the Gulf of Finland was expressed as a curve of the second order. The relationship between the accumulated temperature and the immobile ice extension area in the gulf proved to be similar in character. It will be seen from Figure 2 that with the accumulated temperature of some 450 day degrees the whole of the Gulf of Finland was filled with ice, the area of immobile ice amounting to about 12,000 sq. km, i. e., somewhat less than half the total area of the gulf.

What then accounts for such a course of the curves? The extension of ice in the sea is determined primarily by the amount of heat in the sea, which is known to depend on the depth of the region. A comparison of the course of the curves with the varying depth in the regions of ice formation shows that the curve characterizing the change in the average depth in the ice formation region is in good agreement with the curve earlier obtained for the relationship between the accumulated temperature and the ice extension area in the gulf. Thus, other conditions being equal, the development of ice processes over the Gulf of Finland is closely connected with the depth of the ice formation region. It is noteworthy that the curve of relationship between accumulated temperature and ice thickness accretion is of similar shape (see Fig. 2).

The agreement of all curves obtained indicates that the source of ice processes follows some general law as regards both the accretion of the thickness of ice and its surface extension. The spreading of ice and its increase in thickness takes place when the water masses in the sea are ready for freezing. Thus, given similar hydrographical conditions both these processes in any particular region are affected by the same meteorological factors whose value varies somewhat in space. These factors bring about the formation of ice (crystallization of water): yet in one case the crystallization process proceeds mainly in the horizontal plane, causing the formation of ice over the gulf, whereas in the other it develops in the vertical direction attended by ice thickness accretion. It is evident that with augmentation of the ice volume the distance between the curves characterizing the course of both processes will increase, since with the growth of ice thickness the rate of accretion will diminish.

B.
Biological Section

1.

Measurements of the Primary Production and Recordings of the Water Transparency in the Norwegian Sea during May-June 1958

(Preliminary Report)

By

GRIM BERGE

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Measurements of the primary production in the Norwegian Sea in June 1954 (Berge, 1958) indicated a highly productive area in a mixed water mass with salinities between 34·95 and 35·15 ‰ in the central part of the sea. The Arctic water masses in the northwestern part and the Atlantic water masses with salinities above 35·15 ‰ in the eastern part, showed nearly no production.

There is reason to believe that great variations in the rate of production occur from one year to another. Taxonomical analyses of phytoplankton from these areas in 1952 and 1953 (Ramsfjell, 1957) and 1954 (Paasche, 1959) demonstrate great changes from one year to another both in the qualitative and quantitative composition of the plankton.

The changes are possibly caused by variations in the hydrographical and meteorological conditions. The rate of production in the mixed water masses in the central part of the Norwegian Sea is thus determined chiefly by the state of stability (i.e., the depth of the mixing layer) (Sverdrup, 1953); but the relative amount of inflow, the biological and nutritional conditions in the original water masses should be expected to affect the production to a certain extent.

In order to study variations in the composition of the phytoplankton and in the primary production in relation to changes in the hydrography and distribution of fish, phytoplankton investigations have been continued, together with hydrographical and other biological investigations during the IGY.

Material and methods

From 28. April to 24. June 1958, the area shown in Figure 1 was investigated. Besides measurements of the primary production and sampling of phytoplankton for taxonomical analysis, investigations were made on hydrography and zooplankton. Experiments were also carried out on methods for the immediate indication of the production. Thus, continuous r cording of the water transparency at the 5 m lev was undertaken, and Secchi-disc readings were ma at all stations during the day.

The production measurements were carried o with ^{14}C as indicator (Steemann Nielsen, 195 following the technique described by Berge (1958 This technique is based on the correlation betwe the production (P) and the effective part of th incoming light energy ($\int I_z dt$) (Sverdrup, 1953 $P = k \int I_z dt$.

The correlation factor between P and $\int I_z$ describes the potential production per unit of lig energy (production capacity). Berge (1958) state that the production capacity is a more suitable fact for expressing the relative production than measur ments *in situ* where weather conditions may in fluence the measurements to a great extent. Fro knowledge of the light penetration into the s and a representative $\int I_z dt$ for the area and time question, the production capacity may be converte into total production in the euphotic zone for a average day (Berge, loc. cit.).

Together with the measurements of K, photoelectr light measurements, and simulated *in situ* measur ments of P therefore were made. The latter part the material is not yet ready for presentation.

Measurements of the production capacity

These measurements were carried out at the stan ard depths 0, 10, and 20 m at 142 stations (7 samples). At the first 74 stations of the cruise, sampl were taken with an all glass water sampler (Aab Jensen and Steemann Nielsen, 1953), and productio experiments were carried out in 100 ml glass sto pered water bottles. Later on a new water samp was used, in which the samples were drawn direc into the experimental bottles (Fig. 2), thus avoidi retapping of the sample. After addition of 1 m

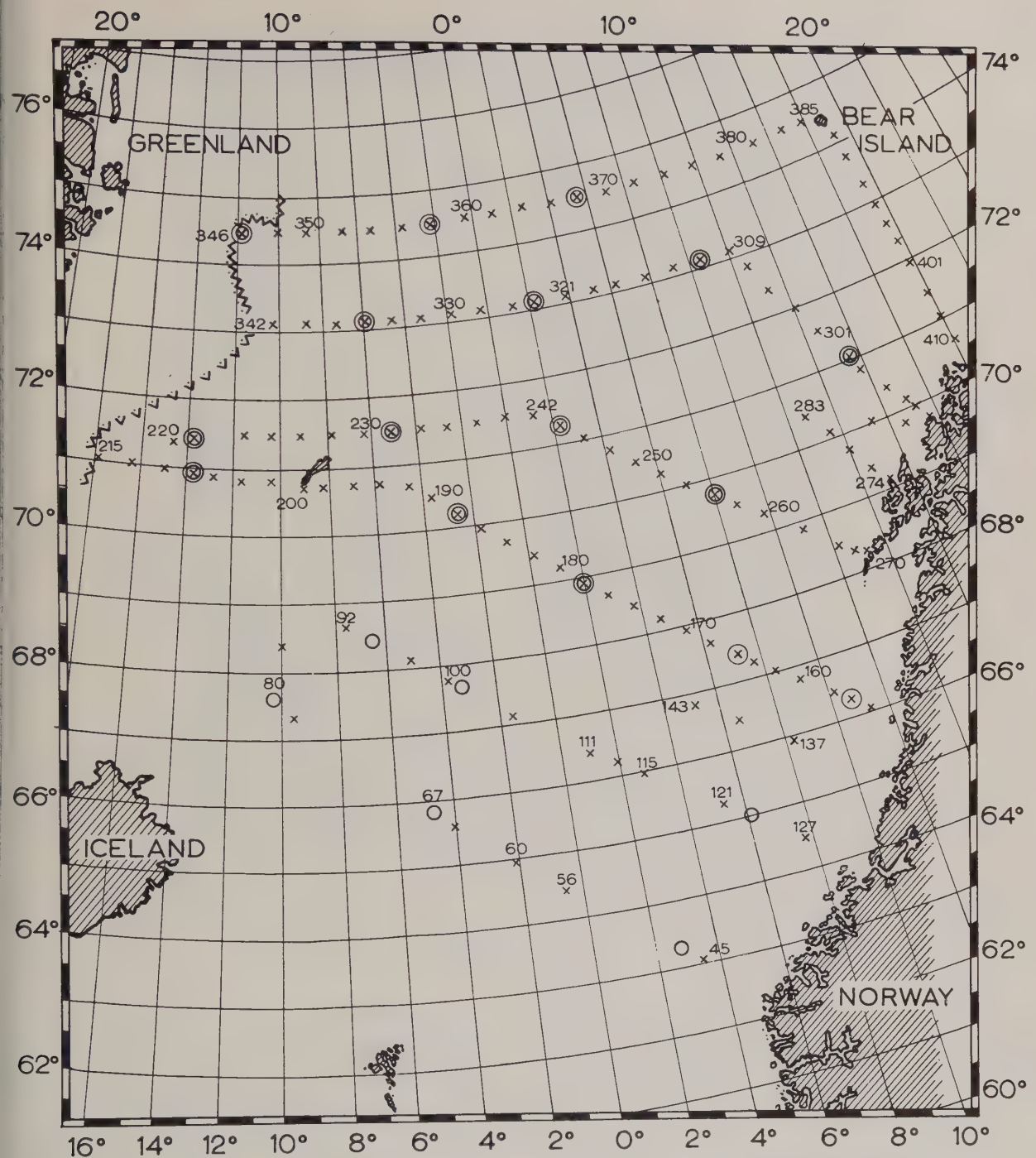

Figure 1. Sections and stations for production measurements in the Norwegian Sea in the period 28. April to 24. June 1958.

× = measurements of production capacity.
○ = simulated *in situ* measurements of production.
◯ = submarine daylight measurements.

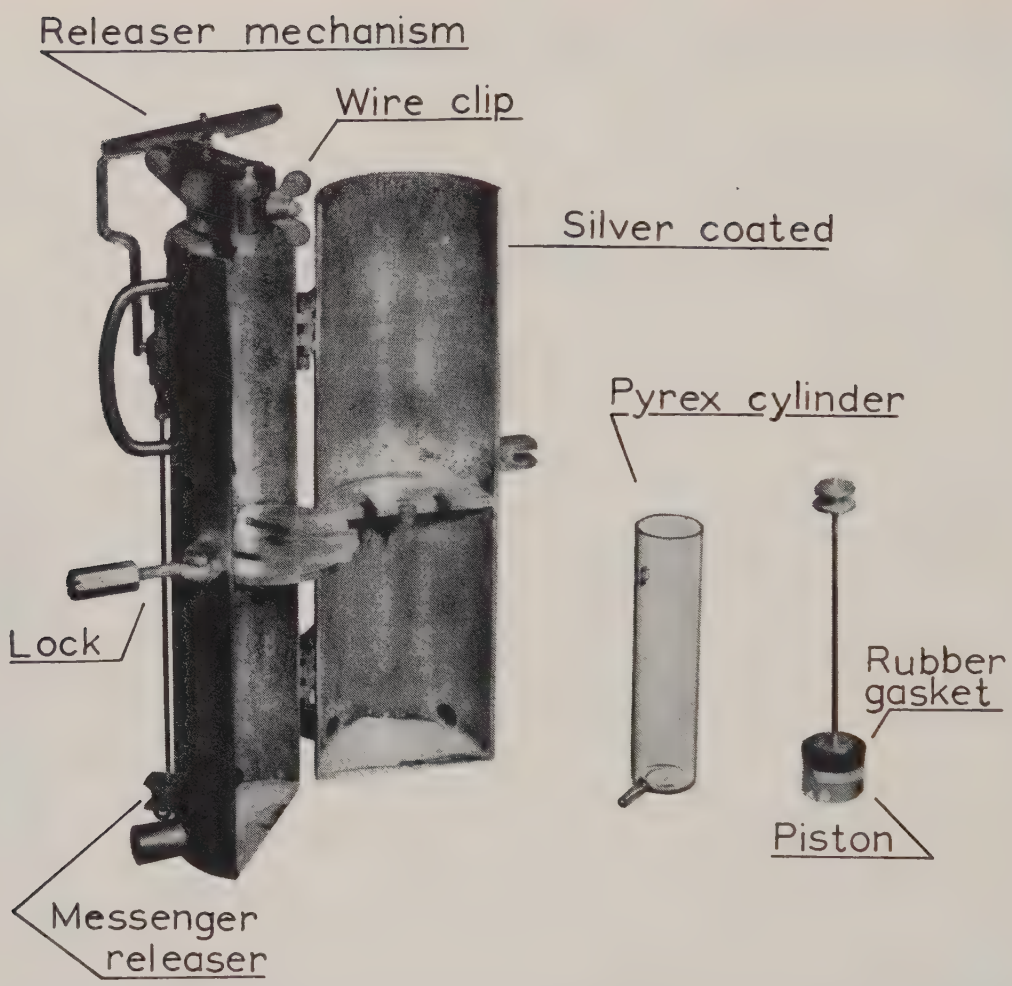

Figure 2. Water sampler for insertion of 4 production bottles. The samples are sucked directly into the bottles, which are constructed after the syringe principle. A messenger and the weight of the sampler operates the mechanism.

$NaH^{14}CO_3$ (type b, Steemann Nielsen, 1952) the bottles were placed in an incubator (Fig. 3) for 4—5 hours. The incoming light energy was recorded by a watertight photocell in the incubator combined with an integrating lux meter. After filtration through a millipore filter (type AA) in a press-filtering apparatus of special construction (Fig. 4), the filters were dried and kept for Geiger counting ashore.

The production capacity (K) was calculated from the following formula:

$$K = \frac{\text{CPM} \times \Sigma CO_2 \text{ mg C/L}}{(\text{CPM})i \times \text{lux-hours}} \times 1{\cdot}1$$

The equation ΣCO_2 mg C/litre was taken from Buch *et al.* (1932). The factor 1·1 is the correction for discrimination and respiration (Steemann Nielsen, 1952); (CPM)i, the total counts in the tracing element introduced into the sample; CPM, the counts of the filter.

The transparency meter

The transparency meter (Fig. 5) has a tube of plexiglass, 1·5 m in length, diameter 10 cm. A water pump, delivering a continuous water flow from a depth of 5 m through the tube, is placed at the bottom of the ship. The instrument is in principle an ordinary turbidimeter with artificial light, but deviates from those constructed by Jerlov (1944) and Joseph (1955) in its fixed position inside the ship as well as in the recording unit. The light source which transmits parallel light is placed at the lower end of the tube and the recording unit at the upper end. The latter consists of a convex lens, and iris dia-

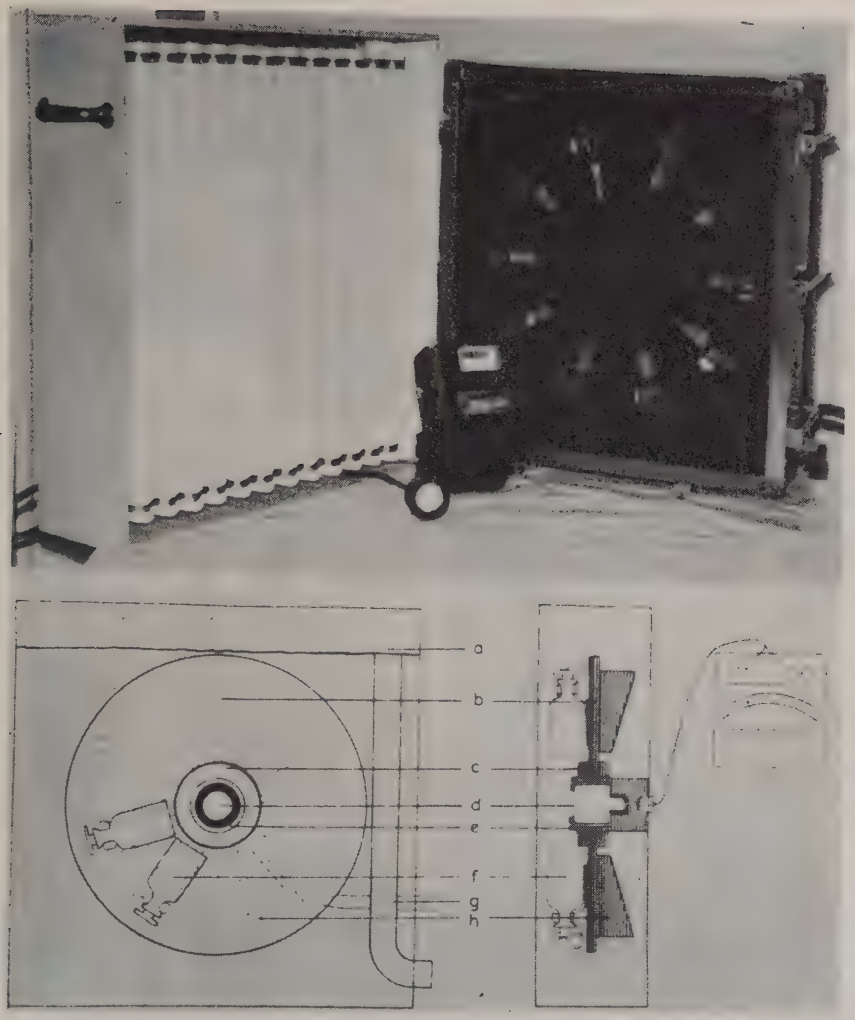

Figure 3. Apparatus for measuring the production capacity.
Upper part: Light source and incubator with the light recorder. Lower part: Two vertical sections of the incubator.
a. Water overflow. d. Photo cell. g. Water inlet.
b. Rotating wheel. f. Sample bottle. h. Turbine wings.
The waterflow rotates the wheel.

hragm to exclude slant incident light, and a photo esistance. The photo resistance (mrk. PETEWE, dr. ng. W. Heimann, Dotzheim, Germany) has a very igh sensitivity and a characteristic (Fig. 6) which nakes it very well suited for the purpose: the sen-tivity, increasing nearly exponentially with decreas-ng light makes it almost equally sensitive for varia-ons in turbid water as well as in clear water. Both ne light source and the iris diaphragm can be ad-usted. By different combinations the sensitivity of ne instrument can be varied. During the latter half f the cruise recordings were made at two different vels of sensitivity.

Results

The production capacities are shown in Figure 8. Similar to the conditions in 1954 a production area, limited by the 34·95—35·15 ‰ isohalines were evidently located in the central part of the Norwegian Sea (cf. Figure 9). The rates of production are however, very different in the two years, the values of 1954 being 2—3 times higher than those of 1958. In the Arctic water masses N and NW of Jan Mayen the situation is almost the opposite, the values in 1958 being 2—3 times higher than those of 1954. The temperature of the Arctic water was also higher than usual.

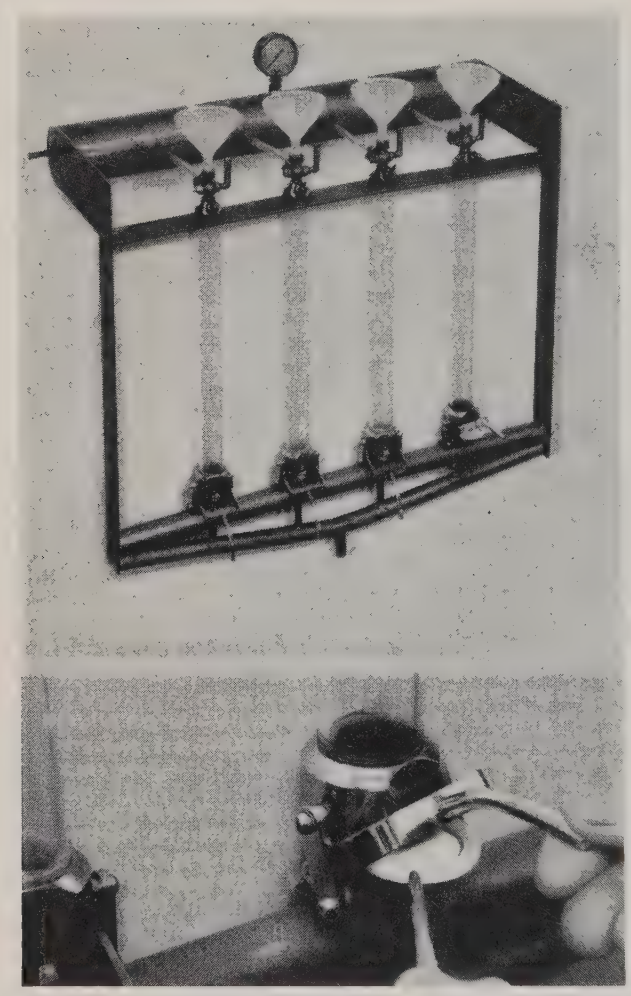

Figure 4. Pressure filtering apparatus for 4 simultaneous and independent filterings. The pressure is obtained by an air pump

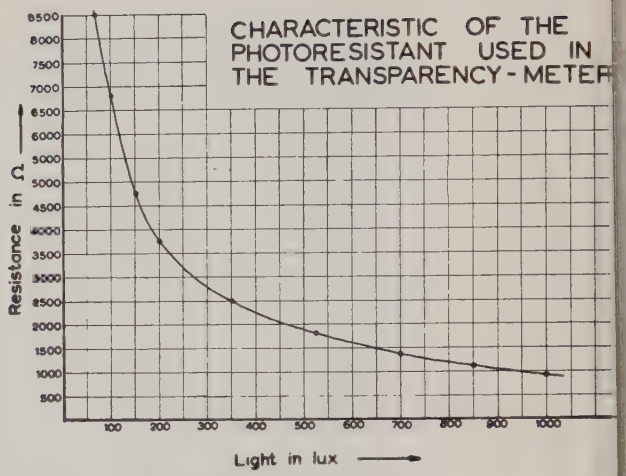

Figure 6. Characteristic of the photoresistant used in the transparency meter.

A marked effect of the "time" factor is demonstrated in 1958, the production capacities within the same water mass decreasing in a south-north direction. This is to be expected since there was an interval of more than two months between the southernmost and northernmost sections.

From the observations on primary production hitherto made in the Norwegian Sea the following conclusions may be drawn:

I. Four areas are distinguished with regard to their rate of production:
   1. Arctic water masses with salinities below 34·95 ‰.
   2. Mixed Atlantic water masses with salinities between 34·95—35·15 ‰.
   3. Atlantic water masses with salinities above 35·15 ‰.
   4. The coastal water masses off Norway.

II. Marked variation in the production capacities is observed to occur in areas 1 and 2.

As the measurements made only indicate certain situations in the production, one may not be justified in drawing any conclusions as to the rate of the annual production. Information of this kind would require measurements several times a year. However, from the results obtained, it seems as if regular observations from one selected station within each of the four production areas would be sufficient to keep track of the annual production.

Until more hydrographical data are available, it is of little value to discuss the possible causes of the variations in the production. As to the production in the mixed Atlantic water masses, however, very interesting data may evidently be observed in the actual mixing area NE of Iceland.

From stations 200—410, recordings of the water transparency were made at two different sensitivity ranges of the transparency meter. The correlation between the recordings at 5 m (resistance readings in ohms) and the corresponding prod. capacities at 10 m for the two sensitivities are shown in Figure 10. In the second diagram (B) most of the corresponding production capacities during the cruise were very near zero. For the sake of simplicity most of the low values have been omitted.

The diagrams show that a fairly good correlation exists between the water transparency and the production capacity (K) for values of K above 1×10^{-7}

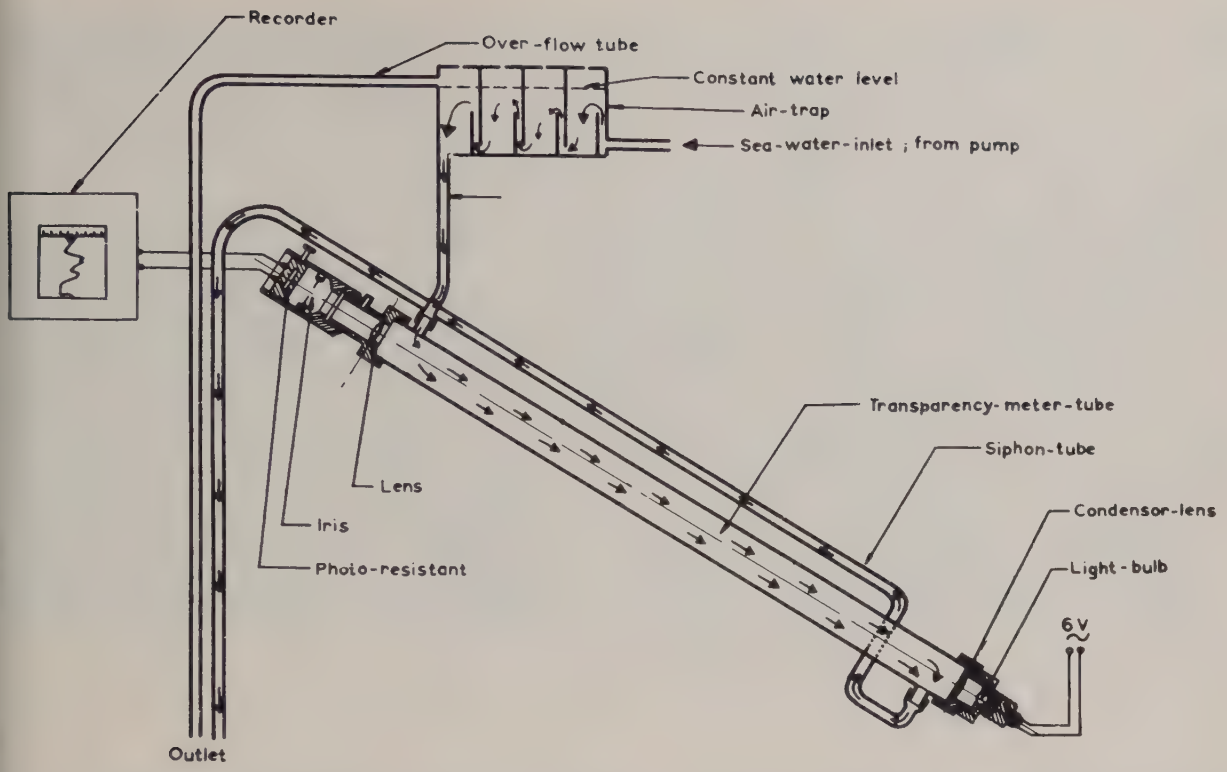

Figure 5. The transparency meter. The tube consists of clear Perspex, 1·5 m long and 10 cm diameter

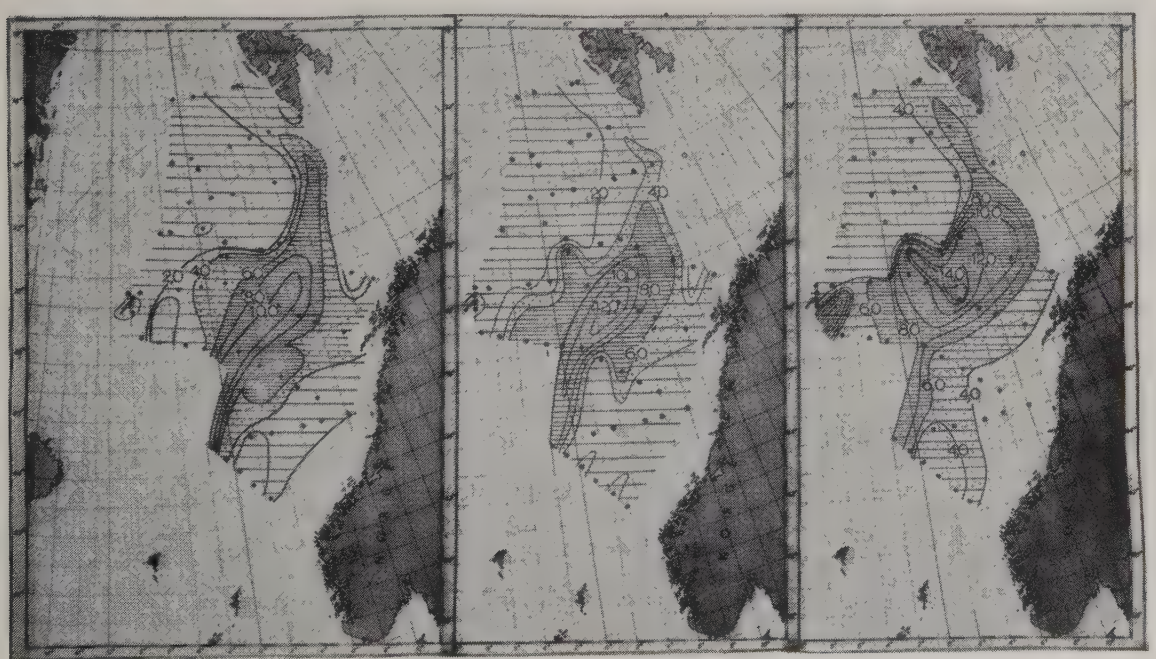

Figure 7. The production capacity (10^{-7} mg C/litre and lux-hour) ,24/V—25/VI 1954, 0— 10 and 20 m (Berge, 1958).

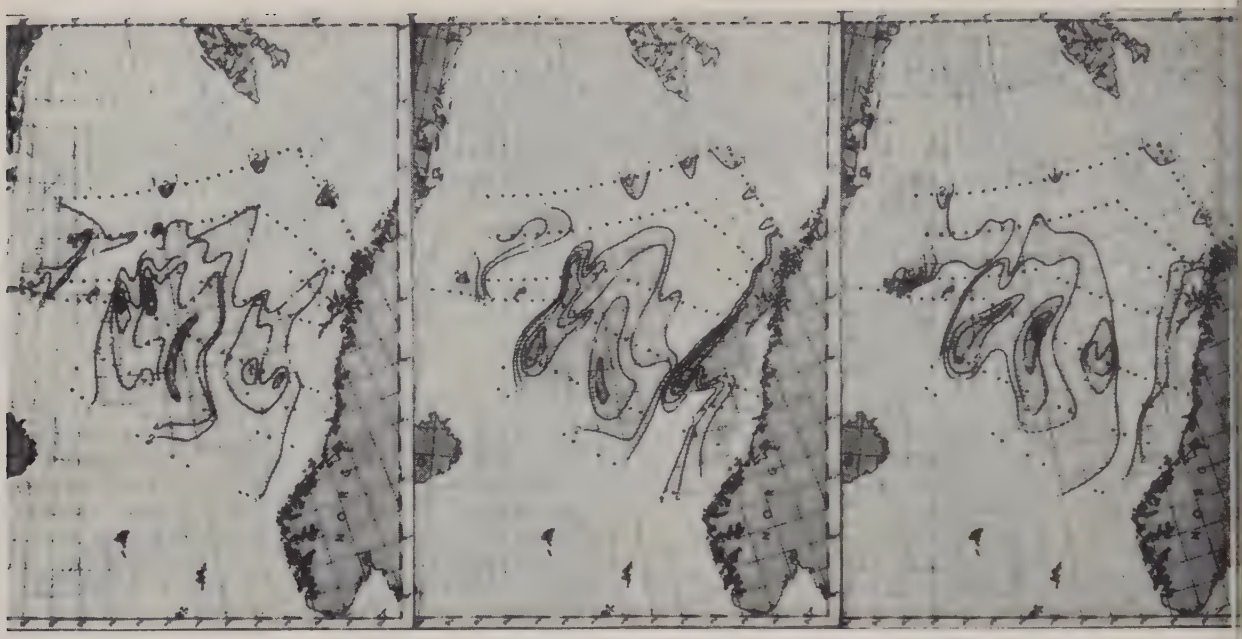

Figure 8. The production capacity (10^{-7} mg C/litre and lux-hour), 28/IV—24/VI 1958, 0—10 and 20 m.

Figure 9A. S $^{0}/_{00}$ in 20 metres, 28/IV—24/VI 1958. (Eggvin, not published).

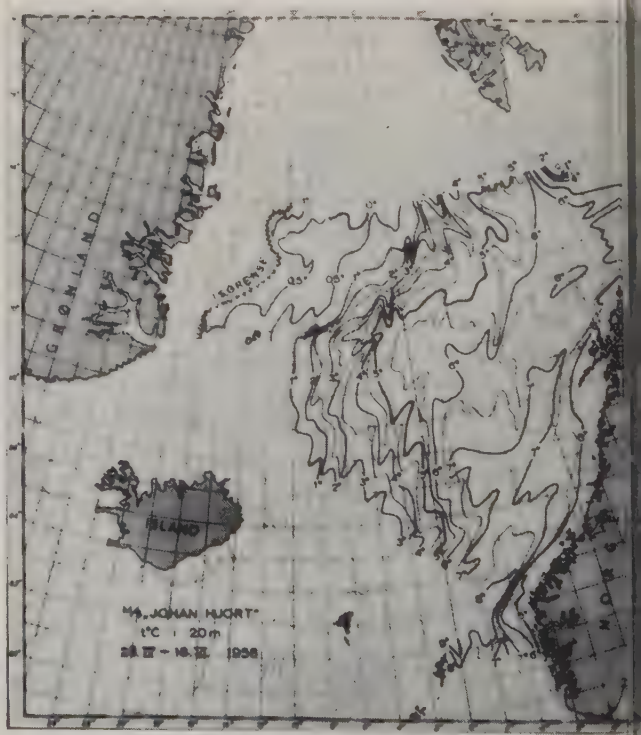

Figure 9B. T°C in 20 metres, 28/IV—24/VI 1958. (Egg
not published).

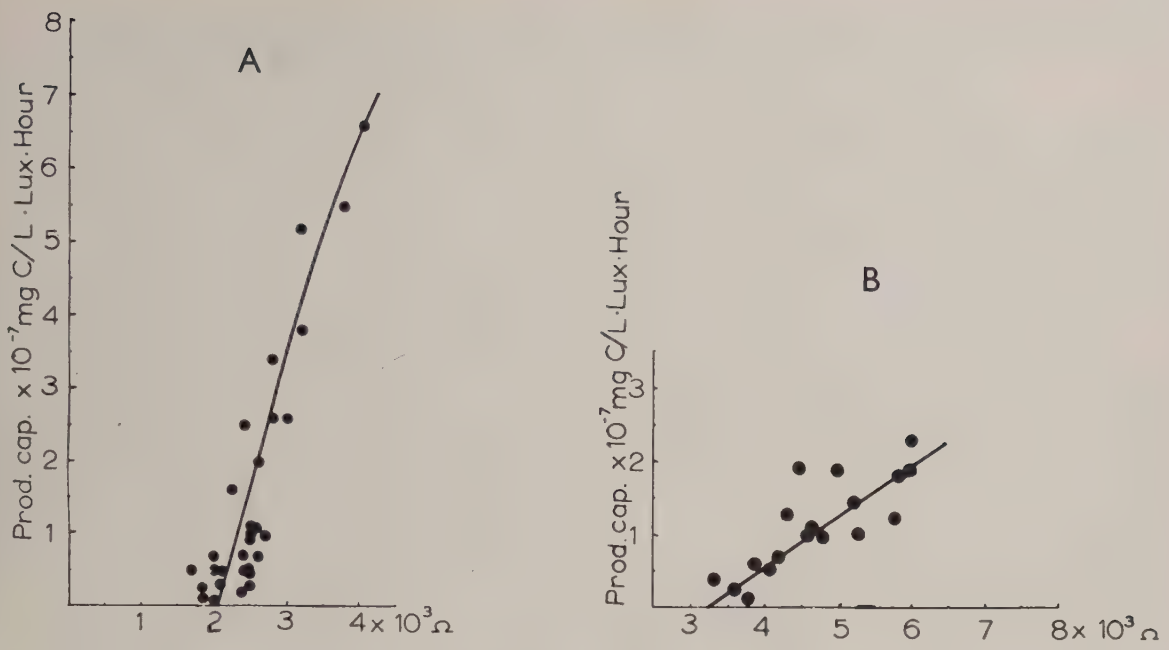

Figure 10A and B. The correlation between the transparency (recordings in ohm, 5 m depth) and the production capacity in 10 m. (A and B, two different sensitivity ranges of the apparatus).

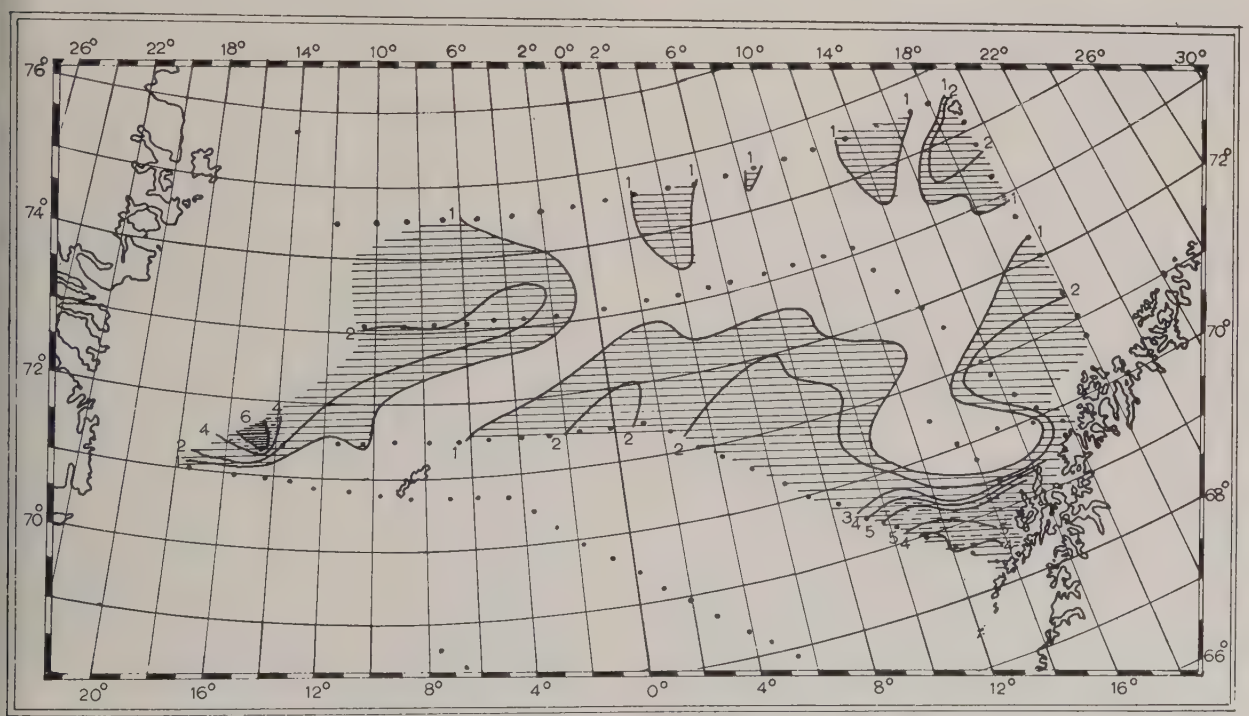

Figure 11. The transparency recordings 28/IV—24/VI 1958, transformed to production capacities × 10^{-7} mg C/litre and lux-hour.

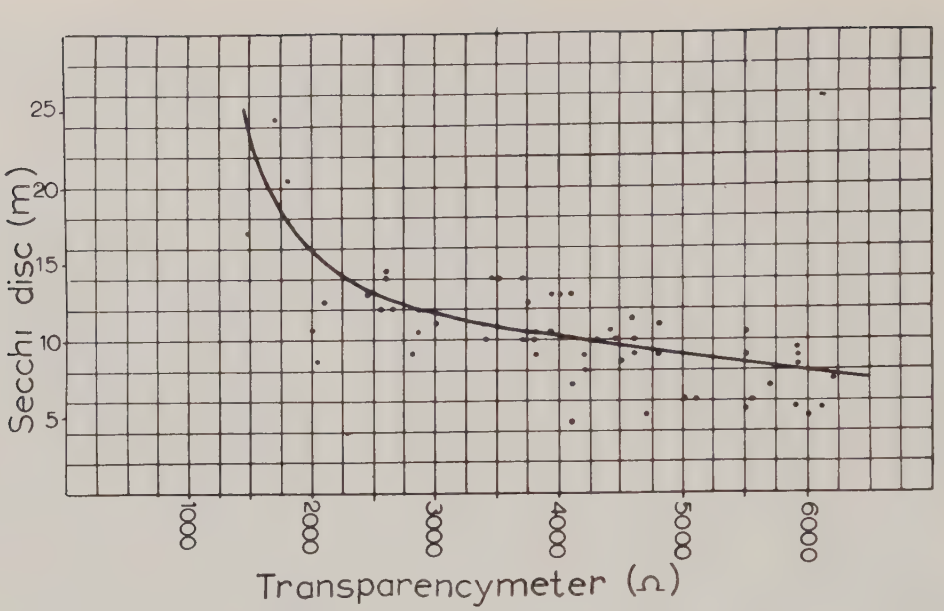

Figure 12. The correlation between Secchi-disc readings in m (only stations between ± 2 hours from noon), and the corresponding transparency recordings in ohms.

mg C/litre and lux-hour. The correlation curve, which seems to be rectilinear can be written as

$$R - R_0 = a \cdot K$$

R = resistance in ohms.
R_0 = resistance in ohms for non productive water.
K = production capacity.
$a = \frac{R - R_0}{K}$ is the specific light absorption for the producing population.

The relationship demonstrates that as long as the actual a for the investigated areas is constant (or varies within limits negligible for the accuracy aimed at) the variations in the photoresistance give directly the relative variations in the production. However, if very different areas are to be recorded, eventual differences in the specific light absorptions for the populations should be estimated. According to the formula above, the a is determined by one accurate ^{14}C measurement simultaneous with the resistance recording within each of the populations. The R_0, which is the resistance response in non productive water, is determined from the correlation in Figure 10, as the value where the extrapolated correlation curve cuts the axes. This value was in the demonstrated case found to be close to that of ion-exchanged tap water, and the instrument could therefore with satisfactory accuracy easily be calibrated with ion-exchanged water in the system.

Figure 11 is demonstrating the production capacities in 5 m, based on the transparency recordings. The recordings have been transformed to production capacities using the correlation from Figure 10. The map obtained corresponds in the main features well with that for 10 m (Fig. 8) based on the measurements with the ^{14}C technique.

From all stations taken ± 2 hrs. from noon the Secchi-disc readings have been correlated with the recordings of the transparency meter (Fig. 12). In most cases there is evidently a correlation between the disc readings and the transparency recordings; discrepancies may chiefly be explained by inaccurate Secchi-disc readings, caused by unfavourable weather.

In the Norwegian Sea where the production capacities vary from $0–14 \times 10^{-7}$ mg C/litre × lux-hour both the Secchi-disc readings and transparency measurements give fairly good and immediate indication of the production. However, the transparency meter has the following advantages:

1. Recordings are made continuously at a certain level, indicating horizontal gradients in the production.
2. Observations are taken during day and night.
3. The instrument is very little influenced by the weather, except in rough sea, when air bubbles in the water disturb the measurements.

In areas where the research vessels are operating regularly, the instrument presented thus may give

valuable information of the relative production at different times of the year. However, since variations in *a* (see above) in certain areas might be of importance, the use of the instrument is recommended in conjunction with selected measurements of the primary production.

Summary

Measurements of the primary production were carried out at 142 stations from 28. IV—24. VI 1958, together with recordings of the water transparency and Secchi-disc readings.

The technique for measuring the production capacity is described and pictures are given of the instruments used. A drawing of the transparency meter is given and the principle for its operation explained.

Maps of the production capacities measured in 1954 and 1958, indicate entirely different production intensities during the two years, although the same production areas can be spotted.

The correlation between production capacity and transparency readings is illustrated, and the conclusion is drawn that the instrument may give fairly good information of the production. The Secchi-disc readings taken within ±2 hrs. from noon in most cases agree fairly well with the recordings of the transparency. For comparison with the production capacities maps based on the transparency recordings are presented.

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2.

The Primary Production in the Waters West of Greenland during July 1958*)

By

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Since 1954 investigations of the primary production in the waters west of Greenland have been carried out in July/August during the annual cruises of the "Dana". The ^{14}C technique has been used. A short preliminary survey of the results from the 1954 cruise has been published (Steemann Nielsen, 1958).

It was shown that very productive water was found off the slope of the West Greenland banks following the core of the warm current. Another productive area was found near the boundary of Baffin Land and the Labrador Polar Current. The water in the centre of Davis Strait was only moderately productive during this time of the year. The same held good for the waters of the East Greenland Current near the coast from Cape Farewell northwards to about 61°N.

The distribution of inorganic phosphate, as presented by Hermann in the *Annales Biologiques* for 1953—1956, shows a picture which in principle, but not in detail, resembles that obtained by investigating the rate of organic production.

In the open sea, the primary production has been measured only once a year during the height of summer; at three coastal stations, the whole annual cycle of production has been measured (Steemann Nielsen, 1958). There is reason to expect that in most open areas west of Greenland a relatively high rate of production takes place in spring or early summer. If we presume that a comparatively high spring or early summer maximum is found in the central part of Davis Strait, variations in the time when this maximum commences may influence the situation found in July. The maximum may either still be declining or the ordinary summer "minimum" may already have been reached. Small variations from year to year in the time during which the investigations are made may also be of some importance. This implies that it is difficult to explain the differences in production found during the five years of investigation.

*) A full account will appear later, presumably in the series Danmarks Fiskeri- og Havundersøgelser, Meddelelser, N. S.

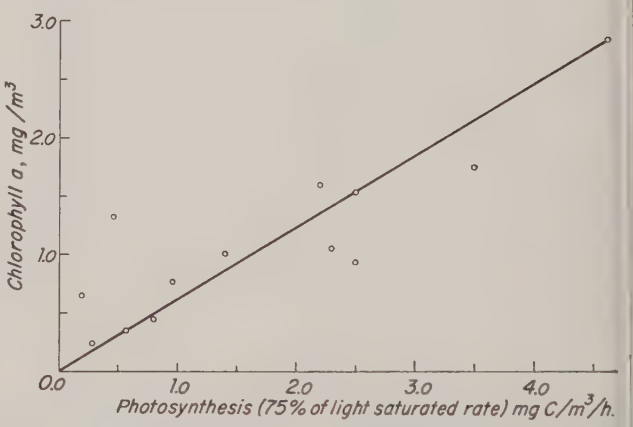

Figure 1. Chlorophyll *a* versus rate of photosynthesis in the waters west of Greenland in July 1957.

Because many investigations were made during the International Geophysical Year it is of special interest to present the situation of the primary production during 1958. A considerable network of productivity stations was therefore occupied during this year. In addition, chlorophyll measurements were also made using principally the Richards and Thompson (1953) technique. Only chlorophyll *a* was measured, however.

Unfortunately all filters containing plankton from the areas in question, measured by the ^{14}C technique, were lost. Only chlorophyll measurements are thus available for stating the productivity situation in the waters west of Greenland during July 1958. Fortunately, measurements of productivity and chlorophyll *a* were also carried out during the cruise in 1957. It was thus possible to correlate the rate of photosynthesis and the chlorophyll concentration for the area (see Fig. 1).

The diagram presents a reasonably high correlation. About 1·62 mg C is assimilated per hour per 1 mg chlorophyll. Only at two stations a considerable deviation from this ratio occurred, indicating very likely a considerable proportion of dead chlorophyll. We may thus suggest that some of the productivity values

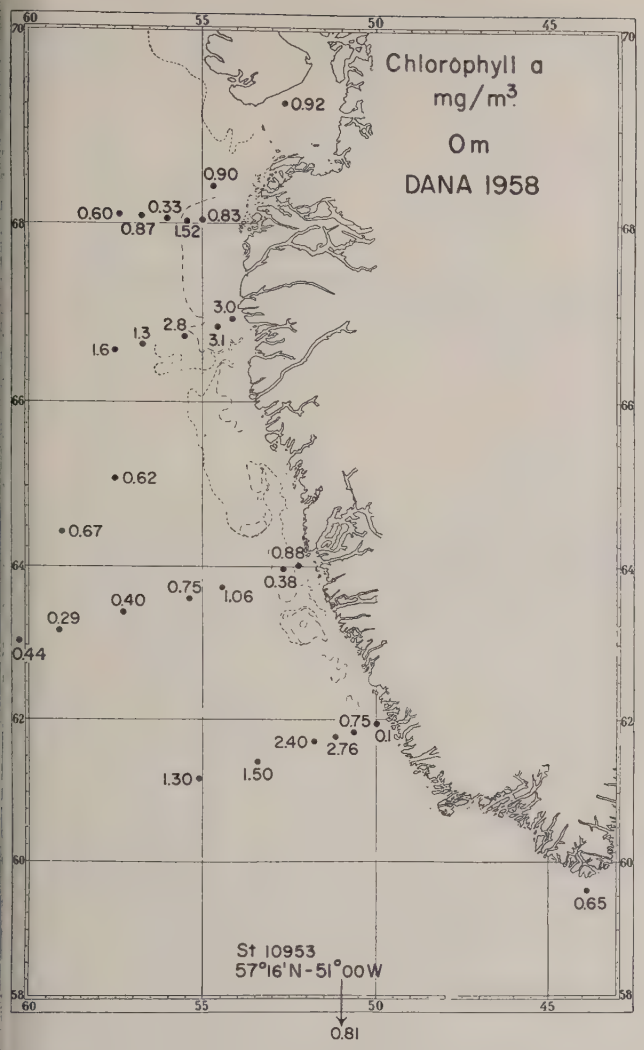

Figure 2. Chlorophyll *a* in the waters west of Greenland in July 1958.

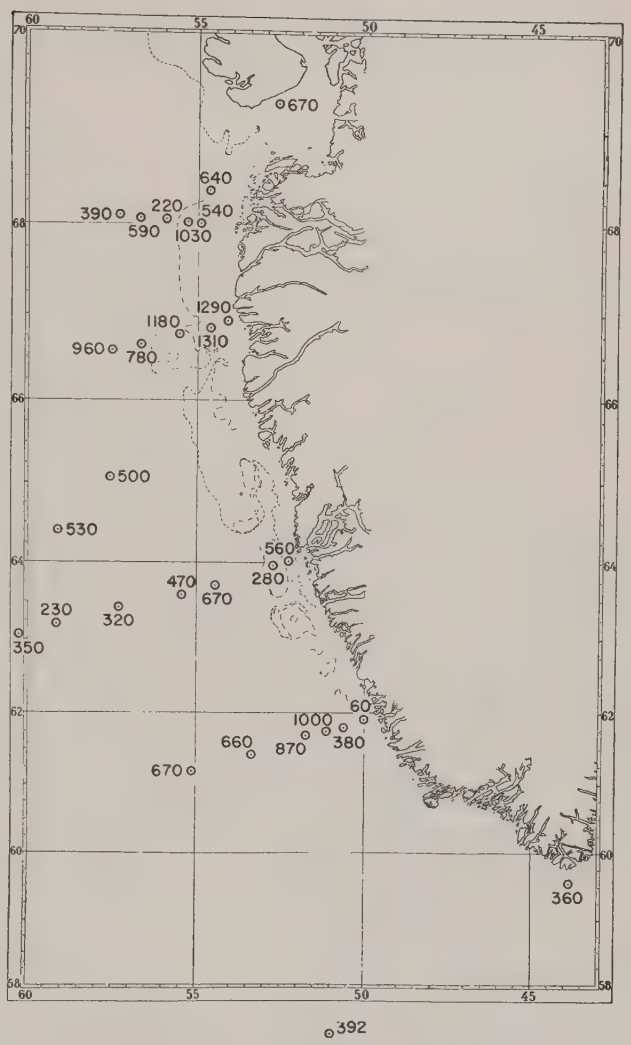

Figure 3. Rate of primary production — mg C/m²/day — in the waters west of Greenland in July 1958.

computed from the chlorophyll measurements in 1958 by means of the photosynthesis/chlorophyll ratio may be somewhat too high. Figure 2 presents the chlorophyll measurements made in West Greenland waters in 1958. Figure 3 presents the estimated productivity values.

In general terms, the rates of production were somewhat lower in the previous four years. This may partly be an artifact due to the occurrence of "dead" chlorophyll, such as mentioned above. However, it must be mentioned that considerably higher chlorophyll concentrations were found in 1958 than in 1957, a year in which the productivity values, generally, were average. There is thus evidence for assuming that the rates of productivity found in July 1958 were, in fact, somewhat higher than those found in most years during that month. It seems, however, impossible to give any conclusive explanation of the fact. The productive water off the West Greenland banks extended further out than in most other years.

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3.

Danish Investigations on the Primary Production and the Distribution of Chlorophyll *a* at the Surface of the North Atlantic during Summer

By

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Every summer since 1954 the Danish Institute for Fishery and Marine Research has carried out investigations on the primary production in North Atlantic and West Greenland waters.

In the North Atlantic three standard sections are worked in the same period every year: —

(1) The Faroe-Shetland section (in the beginning or middle of June).

(2) The section from the Faroes to East Greenland along 62°N Long. (from the end of June to the beginning of July).

(3) The section from Cape Farewell to Ireland (in the second half of August).

Unfortunately the greater part of the material worked in 1958 has been lost, but as the sections are standard sections a summary of our work since 1954 on primary production and standing stock of phytoplankton (measured as chlorophyll *a*) in the North Atlantic gives an outline of the conditions in the periods mentioned.

During these years the purposes and, consequently, the methods have changed.

In 1954/55 the sections were covered with a dense grid of stations in order to get a survey of the productivity in the North Atlantic (in 1954 37 stations, and in 1955 46 stations were occupied). Concurrently and imitated *in situ* method was elaborated (Steemann Nielsen, 1958).

Since 1956 the work has changed. More complicated and time-consuming methods have been used, consequently reducing the number of stations. A method for measuring the rate of respiration of a phytoplankton population by means of the ^{14}C technique has been worked out, and the accuracy of the ^{14}C technique has been tested (Steemann Nielsen and Hansen, 1959 a). In 1957/58 light adaptation in phytoplankton and its interrelation with temperature was investigated (Steemann Nielsen and Hansen, 1959 b). Since 1957 measurements of the concentrations of chlorophyll *a* have been carried out.

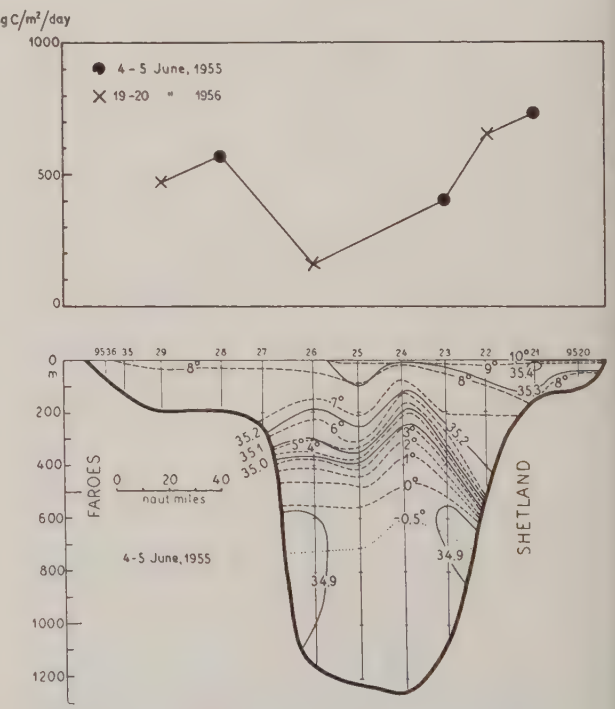

Figure 1. Faroe-Shetland section. Gross primary production, June 1955 and 1956. Hydrography, June 1955. (After Hermann, 1957 a.)

Figure 1 shows the conditions in the Faroe-Shetland Channel. As measurements of the rate of primary production are few in this area I have used those from both 1955 and 1956. The hydrographical section shown in the lower part of the figure is from 1955 (after Hermann, 1957 a).

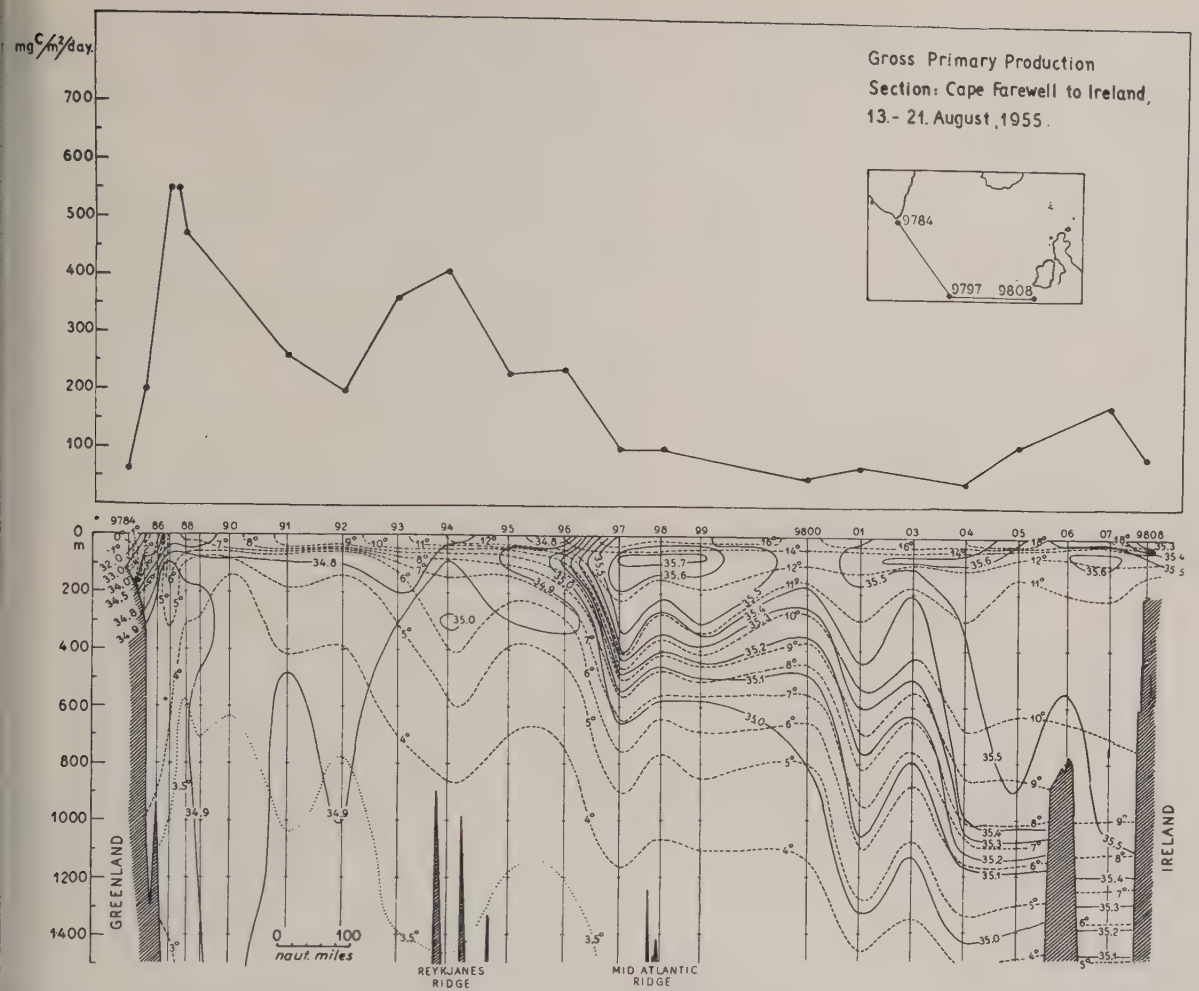

Figure 2. Cape Farewell–Ireland section. Gross primary production and hydrography in August 1955. (After Hermann, 1957b.)

On the shelf on both sides of the channel the water is not stabilized and a considerable production takes place (500—750 mg C/m²/day) during the whole growth period.

Over the deep of the channel both in the north-going current and in the counter current a low rate of production is found, as the supply of nutrients is poor.

The data from the 62° section are also scattered as bad weather conditions frequently make productivity work impossible. A few features are, however, outstanding and constant:—

(1) A high rate of primary production in the coastal waters of the Faroes (about 800 mg C/m²/day). In the area over the Faroe-Iceland Ridge the production is even higher; between 650 and 2700 mg C/m²/day has been measured, caused by the constant upwelling of nutrient-rich deep water.

(2) A low rate of production is found in the East Greenland Polar Current (130—230 mg C/m²/day).

Between these two extremes the rate of primary production may fluctuate from year to year as the changes in hydrographic conditions occur and the time we enter the biological cycle may vary.

A fairly low rate of primary production is usually found in the core of Atlantic water west of the Faroes (140—340 mg C/m²/day) but further westwards, south of Iceland, it may rise to about 800 mg C/m²/day.

In the north-going Irminger Current west of the Reykjanes Ridge a fairly low rate of production is also found, 170—400 mg C/m²/day.

I the south-going branch of the Irminger Current off East Greenland a low rate of production was measured in 1954 (180—224 mg C/m²/day) but in 1955 and 1956 it amounted to between 350 mg and 760 mg C/m²/day.

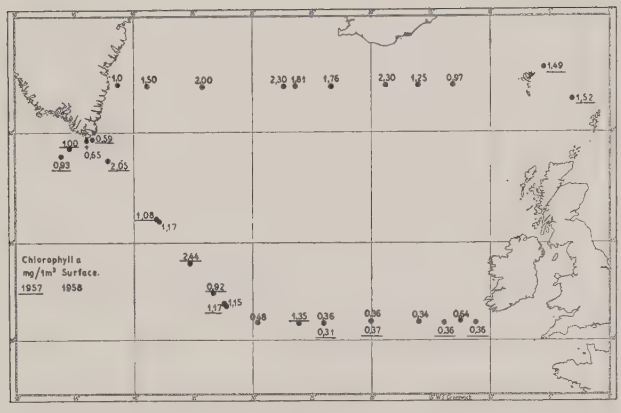

Figure 3. Quantitative distribution of chlorophyll *a* in the surface (mg/m³) in summer 1957 and 1958.

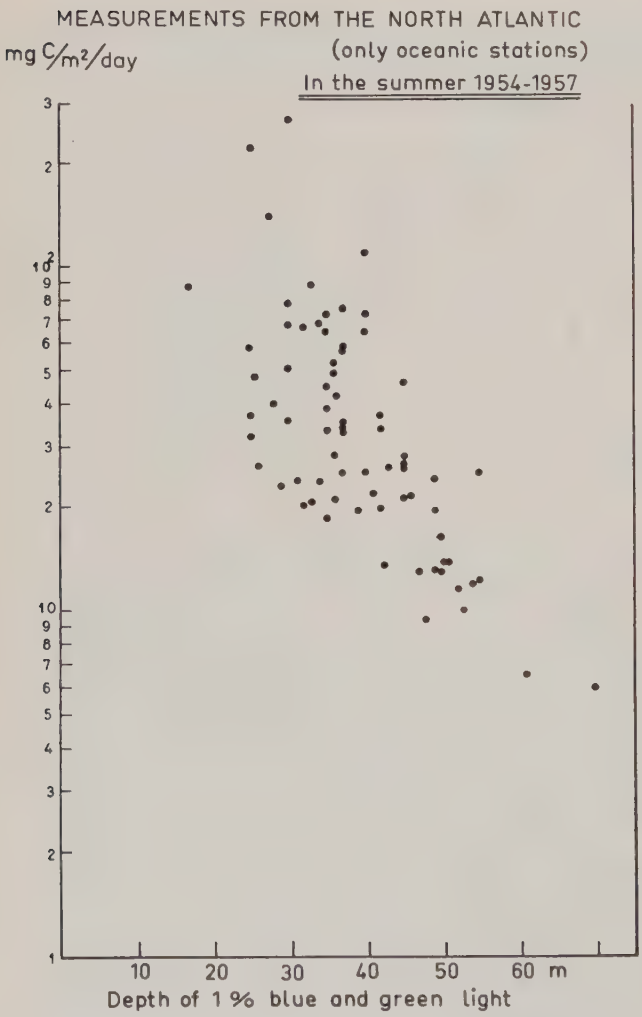
MEASUREMENTS FROM THE NORTH ATLANTIC
mg C/m²/day
(only oceanic stations)
In the summer 1954-1957
Depth of 1 % blue and green light

Figure 4. Depth of photosynthetic layer and maximum rate of photosynthesis per m² surface. Semilogarithmic scale.

As the weather conditions always have been favourable in the periods when the sections from Cape Farewell to Ireland have been worked, a considerable amount of data for the rate of primary production are available from this section.

The same pattern of distribution of areas with a high rate and areas with a low rate of primary production is found from year to year, the exact positions of course being dependent on the variations in the hydrographic conditions.

As an example the conditions in August 1955 are shown (Figure 2). The primary production is computed as mg C/m²/day. The hydrographic section is after Hermann (1957 b).

The section passes through three different water masses with stabilized water:— (1) the East Greenland Polar Current, (2) the great eddy of sub-arctic mixed water south-east of Greenland, and (3) the warm and saline Atlantic water between the North Atlantic Current and Ireland.

Here the greater part of the nutrients is consumed — and lost — in the previous growth period. Consequently, we find a low rate of production in late summer, as low as 50—100 mg C/m²/day.

A high rate of primary production is, however, found throughout the summer in water masses where upwelling of nutrient-rich deep water occurs, viz.:—

(1) In border areas between two current systems, as between the East Greenland Polar Current and the Irminger Current, about 550 mg C/m²/day. In 1955 the production was considerably lower in the border area of the North Atlantic Current, about 250 mg C/m²/day.

(2) Over submarine ridges such as the Reykjanes Ridge (which may rise to 600 m from the surface) and over the slope off Ireland.

As mentioned above, the outlines of areas with high and low rates of primary production are the same from year to year. But the rate of primary production may fluctuate considerably from year to year, as we either may enter at different times in the biological cycle of the water body in question or variations may occur in the hydrographic conditions.

In 1956 the rate of production was of the same order as in 1955 in the whole section.

Since 1954 only slight fluctuations in the rate of production are found in the following areas: (1) the East Greenland Polar Current, (2) the border area between this current and the Irminger Current (530—660 mg C/m²/day, and (3) the eddy of sub-arctic mixed water (200—300 mg C/m²/day). But outside these areas considerable fluctuations occur.

In 1954 the rate of primary production was 2—3 times as great as in 1955/56 over the Reykjanes

Ridge and in the border area of the North Atlantic Current. In 1957 the rate of production was of the same order as in 1954 over the Reykjanes Ridge. But from this area till the stabilized warm and saline Atlantic water east of about 20°W Lat. considerable fluctuations were encountered (between 530 and 1300 mg C/m²/day) caused by unstable hydrographic conditions. In the Atlantic water between 20°—25°W Lat. and Ireland the production in 1957 and 1958 was of the same rate, between about 250 and 400 mg C/m²/day, except at the coastal stations where the rate of production in 1958 was very high, 781 mg C/m²/day.

In 1959 the rate of production of the section east of 35°W Lat. was the lowest one measured since these investigations were started.

Considering the standing stock of phytoplankton, expressed as surface chlorophyll *a* in mg/m³ (Fig. 3), the same pattern of quantitative distribution is found as in primary production. Minima are found in the stabilized water of the East Greenland Polar Current, in the eddy of sub-arctic mixed water, and in the Atlantic water. Maxima are found in the areas mentioned with upwelling of deep water (see above).

In water with a living stock of phytoplankton an inverse proportionality is found between the levels of the compensation depth (depth of 1 % of blue and green light) and both the primary production (Fig. 4) and the concentrations of surface chlorophyll *a* (Fig. 5).

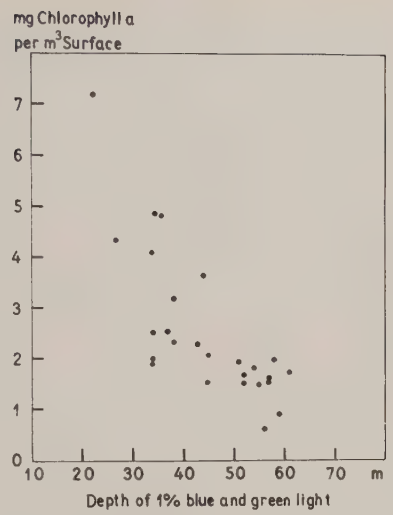

Figure 5. Depth of photosynthetic layer and concentration of chlorophyll *a* at the surface.

In both examples the material is taken from oceanic water in order to avoid too much influence of dead suspended matter, which both reduces the levels of compensation depths and may increase the concentrations of chlorophyll measured.

The close relationship between the concentration of chlorophyll (standing stock of phytoplankton) and the levels of the compensation depths (the turbidity of the water) is quite evident in the samples collected

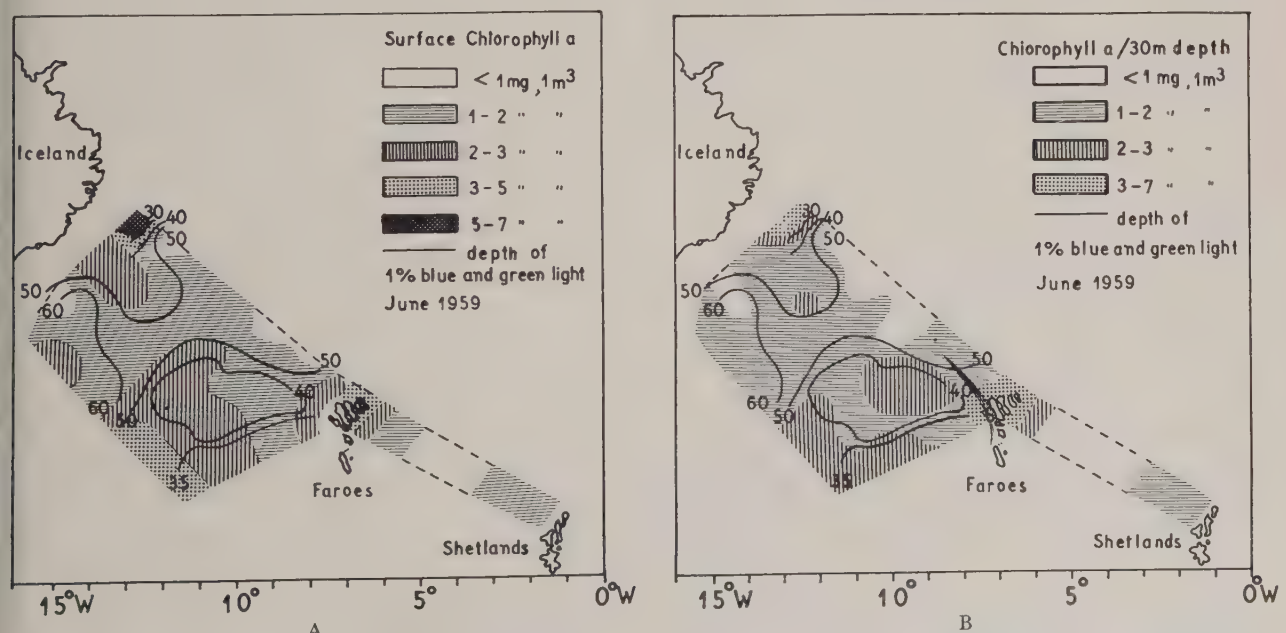

Figure 6. Depths of the photosynthethic layer and
A. Concentration of chlorophyll *a* at the surface. B. Concentration of chlorophyll *a* at 30 m depth.

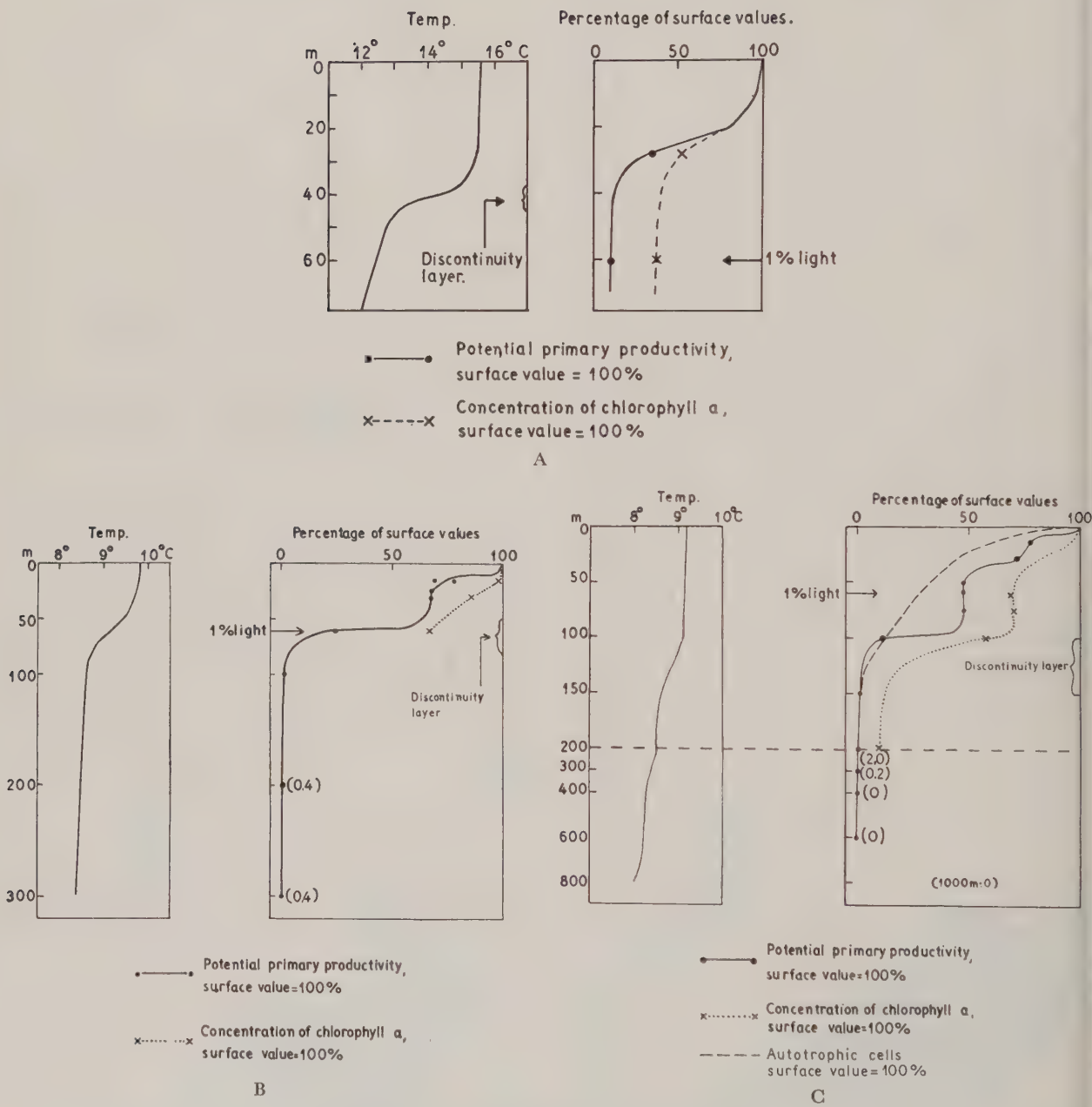

Figure 7. Depths of compensation depth and discontinuity layer in relation to potential productivity and concentration of chlorophyll *a*.

A. "Dana" St. 10.988
B. "Dana" St. 11.205
C. "Dana" St. 11.194

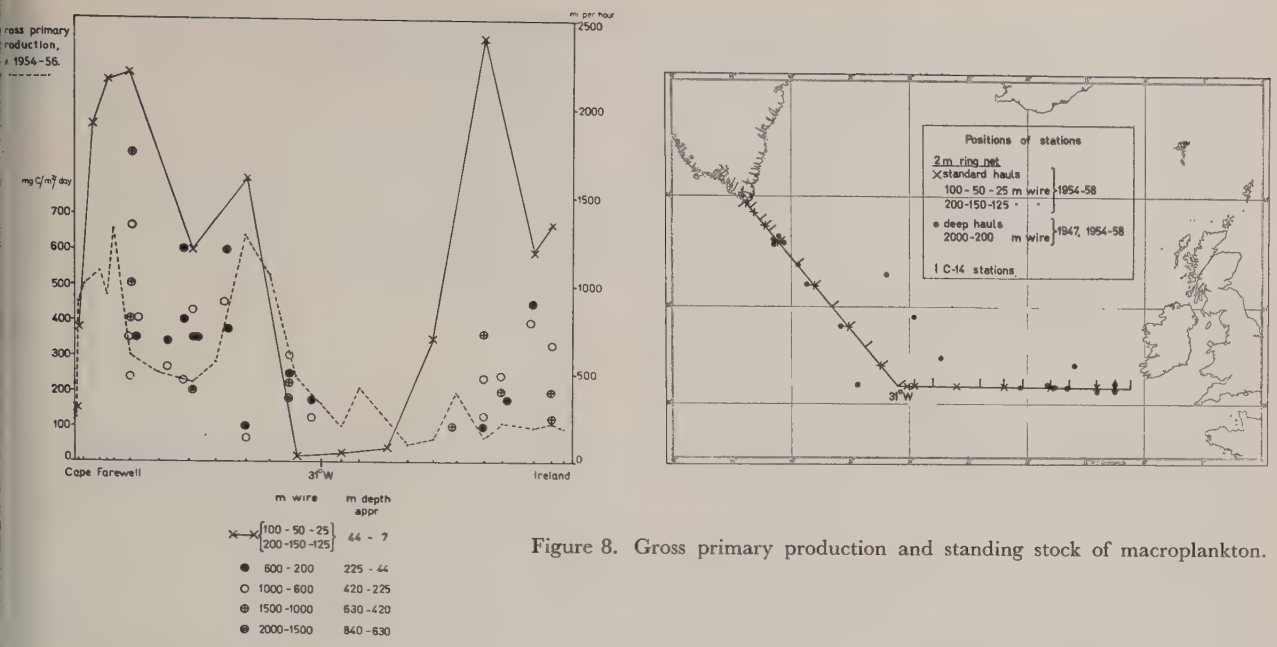

Figure 8. Gross primary production and standing stock of macroplankton.

In June 1959 between the Shetlands and Iceland (Figures 6 A and B). These samples further demonstrate the difference in productivity on the section of the Faroe-Shetland Channel and that of the channel between the Faroes and Iceland, where an almost unbroken submarine ridge connects the islands.

According to the hydrographic conditions mentioned above, only small concentrations of chlorophyll (and a low rate of primary production) are found in the middle part — over the deep water — of the Faroe-Shetland Channel.

The conditions are quite different in the channel between the Faroes and Iceland where the submarine ridges cause upwelling of nutrient-rich deep water, especially in the eastern part, a result of Corioli's force. Consequently the best growth conditions, the greatest stock of phytoplankton, a shallow level of compensation depth, and a very high rate of primary production is found here.

Comparing the productivity and the standing stock of phytoplankton in stabilized waters the interdependence of the levels of the compensation depths and the thermocline is very important. In Figure 7 examples of the three possibilities of the interdependent positions of the two depths are shown: —

A. The thermocline is above the compensation depth.
B. The thermocline is at the same level as the compensation depth.
C. The thermocline is below the compensation depth.

The surface values are put at 100 % in productivity and chlorophyll *a* concentration. The curves of both measurements have identical courses. The level of decrease in both productivity and concentration of chlorophyll *a* coincides with the level of the thermocline. At Station 11.194 (C) the compensation depth is found mid-way between the surface and the thermocline. The turbulence in the level between the 1 % depth and the thermocline is of such effect that the production and loss of plankton algae are equal in the whole 50 m column of water.

Cushing (1959) has described the oceanic production as a predator/prey process and has neglected the "natural" mortality (caused by sinking and decay) of the phytoplankton.

The decrease in productivity as well as in the concentration of chlorophyll *a* near and in the thermocline is probably caused by accumulation of the combined effect of ceasing turbulence and herbivorous zooplankton in these strata. In the sea, observations carried out by different methods (plankton hauls, optical measurements, and echo-sounding) have revealed a considerable and constant accumulation of seston and plankton (Hansen, 1951; Joseph, 1955; Krey, 1954; Wüst and Brogmus, 1955).

Multiple thermoclines with coinciding echo layers are also recorded both in surface layers (Trout *et al.*, 1952) and in deeper layers (Herdman, 1953, and own observations). Experiments have confirmed an accumulation of copepods in discontinuity layers (Harder, 1954).

In some areas with stratified waters as in Kiel Bay it has, however, not been possible to demonstrate accumulations of this kind (Banse, 1957). No doubt,

the mortality rate of the plankton algae due to grazing causes the shown vertical distribution of the standing stock of phytoplankton and the potential productivity in relation to thermocline.

The relation between the quantitative distribution of zooplankton and the primary production in the section from Cape Farewell to Ireland is shown in Figure 8. The dotted curve of the average values of gross primary production for the years 1954/56 (in August) is plotted against the average values of catches taken with a 2 m ring-net in the upper 44 m in 1954/58 (full curve). The deep hauls are so few that the catches are given separately.

With the exception of the large stocks of zooplankton west of Ireland a good agreement is found between the primary production and the stock of zooplankton both in the upper water layers (upper 44 m) and in the deep water.

The greater part of the abundance of zooplankton in the upper 44 m west of Ireland is chiefly caused by a few large catches — as in 1954 — of *Thalia democratica* and Doliolidae. More than 95 % of the stock consisted of these species.

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4.

On the Variation in the Pattern of Free Amino Acids in the Skeletal Muscle of Freshly Caught Oceanic Fish from Different Localities*)

By

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We have known for a long time that the amino acids in the tissues are found not only in proteins and peptides but also unbound. According to Florkin (1956) the invertebrates contain more free amino acids than the vertebrates, and the marine animals show a higher level than the freshwater species. The intracellular system of free amino acids is supposed to have a specific composition in the muscles of each species so that the individual species differ in this pattern.

Ranke (1956) has worked on the pattern of free amino acids in the muscle of freshwater and coastal-water fish. He concludes that all the species examined present qualitatively the same composition of these substances but that the amounts of the individual amino acids differ in the various species.

*) Dedicated to Prof. Dr. A. Bückmann on his sixtieth birthday

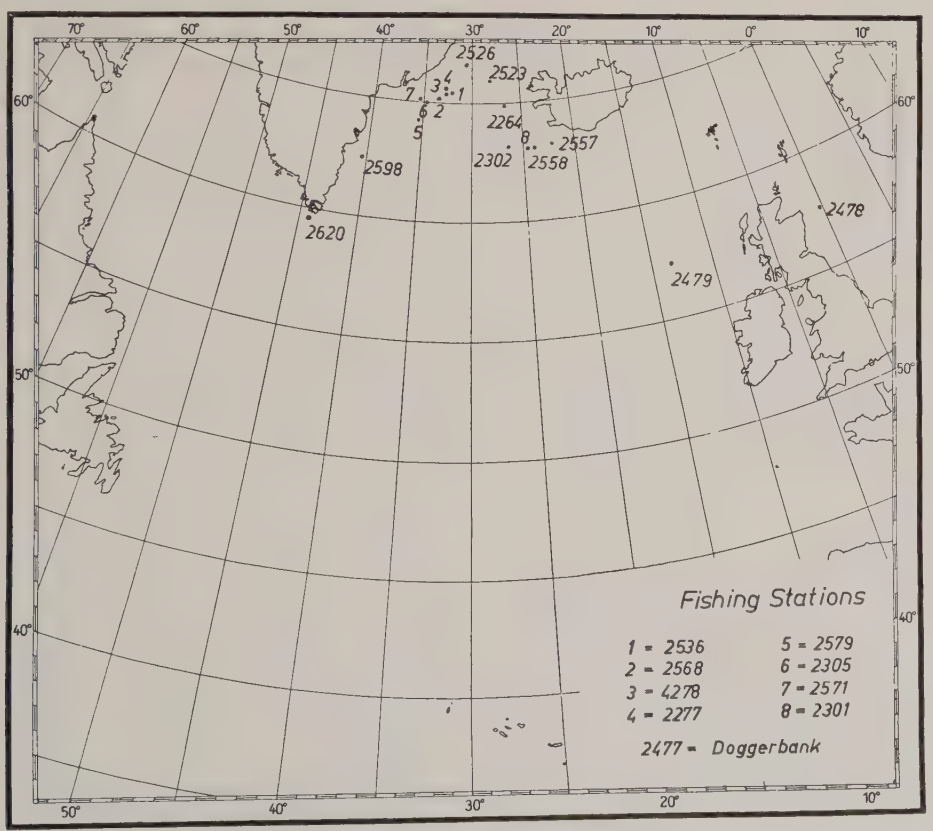


Figure 1. Fishing stations.

Table 1. Content of free amino acids in muscle extracts of fish, mg in 100 mg Kjeldahl-N

Species	n.p.s.	gly-se	glut.	al-thr	valine	proline	hist.
Redfish station 2278							
Sebastes marinus ♂♂ 50 cm	122	16·1	1·5	5·9	0·6	1	1
	148	13·3	3·0	9·6	0·9	2	1
	173	12·8	1·1	9·7	1·0	1	1
	191	15·2	2·8	12·0	1·0	2	2
	171	19·9	5·8	9·4	0·8	1	1
	171	23·5	3·4	6·4	0·6	1	2
	166	20·6	0·8	5·0	0·4	3	2
	172	18·4	0·8	8·0	0·6	3	2
Range of concentrations	122–191	12·8–23·5	0·8–5·8	5·0–12·0	0·4–1·0	1–3	1–2
Cod station 2620							
*Gadus callarias**)							
♀♀ 2 years	66	2·8	0·3	3·8		2	1
2 years	65	4·9	0·9	12·6		2	1
3 years	80	13·7	2·1	9·3		2	1
5 years	68	10·6	0·2	7·3		1	1
6 years	42	11·2	1·0	11·0		1	1
8 years	66	4·2	0·2	2·3		1	1
9 years	50	6·9	0·2	5·6		1	1
9 years	47	3·6	0·2	1·2		1	1
13 years	49	3·0	0·9	6·6		2	1
Range of concentrations	42–80	2·8–13·7	0·2–2·1	1·2–12·6		1–2	1
Haddock station 2479							
Melanogrammus aeglefinus							
23 cm	70	12·0	1·5	6·4	0·6	3	5
29 cm	46	15·2	2·8	10·1	1·4	3	1
33 cm	41	9·6	1·1	4·7	0·4	2	1
40 cm	65	4·6	2·2	8·2		5	1
45 cm	3·9	3·9	0·7	4·7	0·6	2	1
Range of concentrations	41–70	3·9–15·2	0·7–2·8	4·7–10·1	0·4–1·4	2–5	1–5

Abbreviations: n.p.s.: total ninhydrin positive substances — gly-se: glycine-serine — glut.: glutamic acid — al-thr: alanine-threonine — hist.: histidine.

*) I thank Dr. Arno Meyer for the age determinations.

Since oceanic fish have been mainly examined after having been landed (Ranke and Bramstedt, 1955; Dietrich, 1956; Ranke, 1957; and others) it has proved necessary to study the occurrence of free amino acids in the fish immediately after capture.

Materials and methods

Taking part in the research expeditions of R/V "Anton Dohrn" in the International Geophysical Year, samples of muscle from a great number of species were collected in the North Atlantic (Fig. 1). In accordance with Ranke's method (1956) the dissected muscles were placed immediately in alcohol, homogenized in a "Starmix", and preserved by the addition of some drops of chloroform. The alcoholic extracts were analysed by two-dimensional paper chromatography. A preliminary estimation of the quantities of the amino acids was first carried out by arranging them into five groups (very weak — very strong), based on the size and colour of the spots on the paper chromatograms. This is called method 1 (see Schaefer, 1959).

In order to see whether the results with method 1 are reproducible the concentrations of some amino acids were determined using the method of Bode *et al.* (1952). This is here called method 2. The ninhydrin coloured spots of the amino acids were sprayed with a copper solution, the copper complex was eluted and measured at a wave length of 504 mμ. Some amino acids could not easily be separated. In these cases two substances with the nearest Rf-values (glycine-serine, alanine-threonine) were determined. Proline, histidine, and arginine were detected with special reagents and the content in their spots were compared with spots of known concentrations.

Results

On the paper chromatograms (method 1) it can be seen that the sizes of the spots of the different amino acids vary only slightly from fish to fish within the same species, namely by one concentration group. With proline, histidine, and leucine/isoleucine a greater variation can be noticed in some cases (Schaefer, 1959).

The biological variations of the total ninhydrin positive substances to which belong especially the amino acids, taurine and some peptides, and of some free amino acids in the individuals of three species are shown in Table 1 (method 2). Comparing the values of the amino acids in these species we find great differences between redfish and the two other types. Cod and haddock have nearly a similar pattern. No difference can be seen in the various ages or body length.

Florkin has already proved that the pattern of the free amino acids in evertebrates is influenced by environment. He was able to measure differing concentrations of several amino acids under the influence of changes of temperature and salinity of the surrounding waters. This probably means that some amino acids, particularly proline and glycine, play an important role in the osmoregulation. Ranke (1956) reached a similar conclusion in his experiments with various species of fish.

This led to investigations to find out whether fish of a given species occurring in different fishing places (which might mean different environments), show contrasting composition of the pool of free amino acids. Samples of muscle of various species of fish caught in several localities are therefore analysed. The main part of this research was made on redfish and cod since it was possible only to obtain a few specimens of other species from a small number of fishing places. These latter analyses confirm, however, the results of those made on redfish (Schaefer, 1959) and cod.

At several localities, the total ninhydrin positive substances show no important variations neither in redfish (Figure 2) nor in cod (Figure 3) the range of concentrations being too large to find clear differences. This is also the case for glutamic acid (Figure 4).

More evident divergences, however, are found in redfish from various stations with regard to the content of total extract nitrogen (Figure 5) and of free glycine-serine and alanine-threonine (Figure 6). The amounts of proline and less of histidine (Figure 7) differ especially in the summer catches. These divergences in the concentrations are greater from fishing place to fishing place than in individual fishes

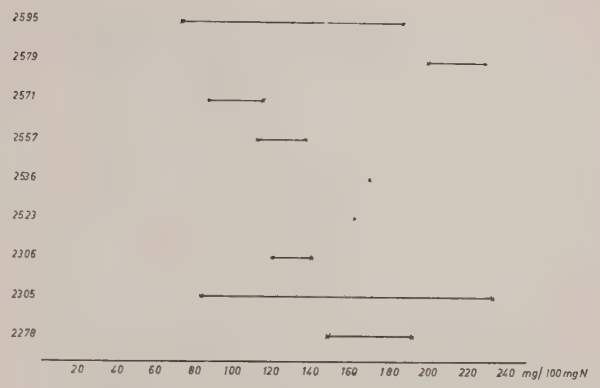


Figure 2. Content of ninhydrin positive substances in muscle extracts of *Sebates marinus* from various stations.

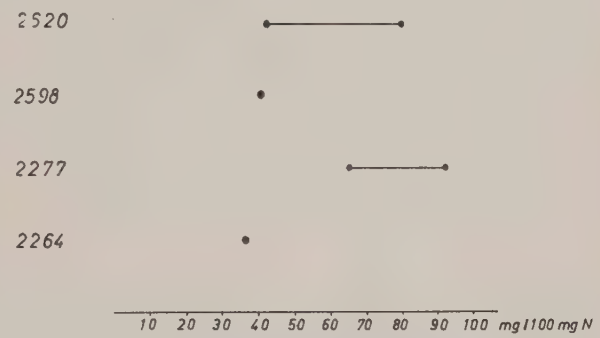


Figure 3. Content of ninhydrin positive substances in the muscles of *Gadus callarias* from various fishing localities.

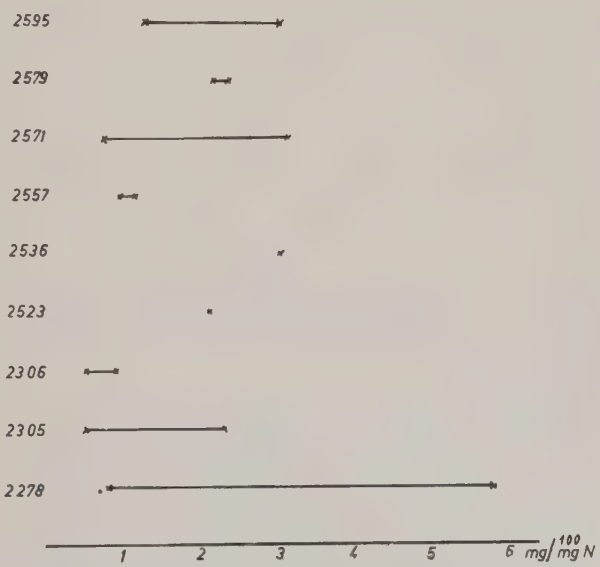


Figure 4. Content of free glutamic acid in *Sebastes marinus* from various stations.

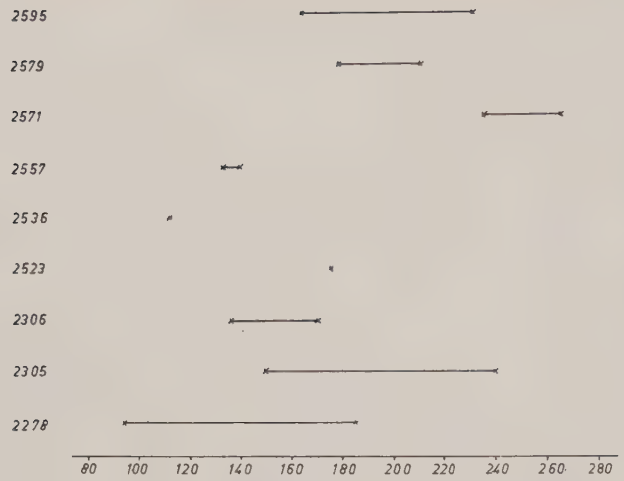


Figure 5. Content of Kjeldahl-N in muscle extract of *Sebastes marinus* from various stations (mg/100 mg fresh muscle).

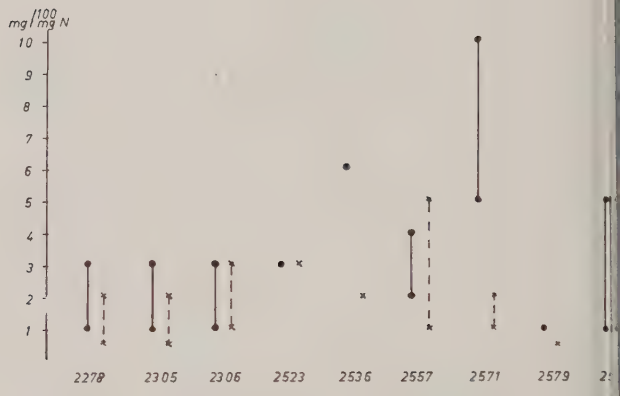


Figure 7. Content of free proline and histidine in *Sebastes marin* caught in various fishing localities.
•——• = proline. ×-----× = histidine.

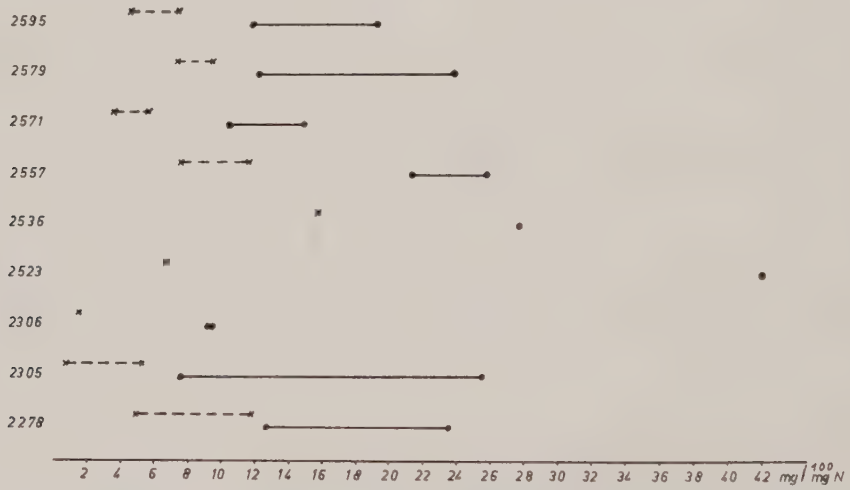


Figure 6. Content of free amino acids in *Sebastes marinus* caught in various fishing localities.
•——• = glycine-serine. ×-----× = alanine-threonine.

from the same locality. The analyses carried out by method 1 show that there might furthermore be deviations concerning arginine and leucine/isoleucine whilst no clear difference is noticed in the other amino acids.

Similar results are obtained for *Sebastes mentella* Travin. Fishes of this species (here it is not a matter of interest if *Sebastes mentella* is a true species or only a subspecies of *S. marinus* L., the common redfish) were caught also at several localities in summer and winter.

The samples of cod caught at different localities show, too, greater variations in the concentrations of glutamic acid and proline (Table 2). The results obtained by method 1 let one assume that differences in concentrations seem to occur also in serine, β-alanine, and taurine. At one station only, hydroxy-proline could be detected, which is a qualitative deviation.

In *Drepanopsetta platessoides* Fabr. (= *Hippoglossoides platessoides* Fabricii), *Trigla gurnardus* L. and *Brosmius brosme* Asc., the estimated values of proline vary at different stations from about 2 to 10 mg, respectively 1 to 8 mg/100 mg N, as seen by the isatine reaction. The arginine contents in *Drepanopsetta,* according to the Sakagushi reaction, lie

Table 2. Free amino acids in *Gadus callarias* caught at different stations

Station	Date	glut.	proline	Estimation from spot size: serine	taurine	β-ala	0-pro
2264	16/III	4·1	1	+++++	+++++	+++++	–
2277	19/III	3·0	1·5	++++	+++++	+++++	–
2598	10/IX	0·9	10	++	+++	++	+++
2620	15/IX	1·0	1·5	++++	+++++	++++	–

Abbreviations:
glut. = glutamic acid
β-ala = β-alanine
0-pro = hydroxyproline
mg/100 mg total extract N

+++++ = very strong
++++ = strong
+++ = medium
++ = weak
+ = very weak
– = not detectable

Table 3. Comparison of the concentrations *within* and *between* the stations

Sebastes marinus, winter: 3 stations; summer: 6 stations

Substance	Winter: Number of fish	Winter: F distribution	Winter: Level of significance	Summer: Number of fish	Summer: F distribution	Summer: Level of significance
n.p.s.	14	0·67	–	12	2·84	–
N	26	4·88	5 %	12	2·2	–
gly-se	14	2·23	–	12	7·36	5 %
glut	14'	1·52	–	12	0·7	–
al-thr	14	14·08	0·1 %	12	6·51	5 %

bb reviations: see Table 4.

between about 2 and more than 10 mg at two localities. Furthermore, the content of β-alanine (value estimated according to chromatograms with known concentrations) in *Drepanopsetta* differs very much at two stations, the variation is to be considered from about 1 to more than 10 mg/100 mg N (Figure 8).

Statistical evidence*

Since the method applied in this study is provided sometimes with larger errors it is necessary to elucidate whether the errors are greater than the biological variability within the fish of each station. The variances of the biological variability (s_1^2) are compared with those of the methodical errors (s_2^2) of the fishes of each station (distribution of F). The result for *Sebastes marinus, S. mentella,* and *Gadus callarias* is that the biological fluctuations are significantly higher than the errors.

Then it must be stated if the differences of the values *within* the single stations are smaller than the differences *between* the various stations. The results for *Sebastes marinus,* separated in winter and summer catches, are given in Table 3.

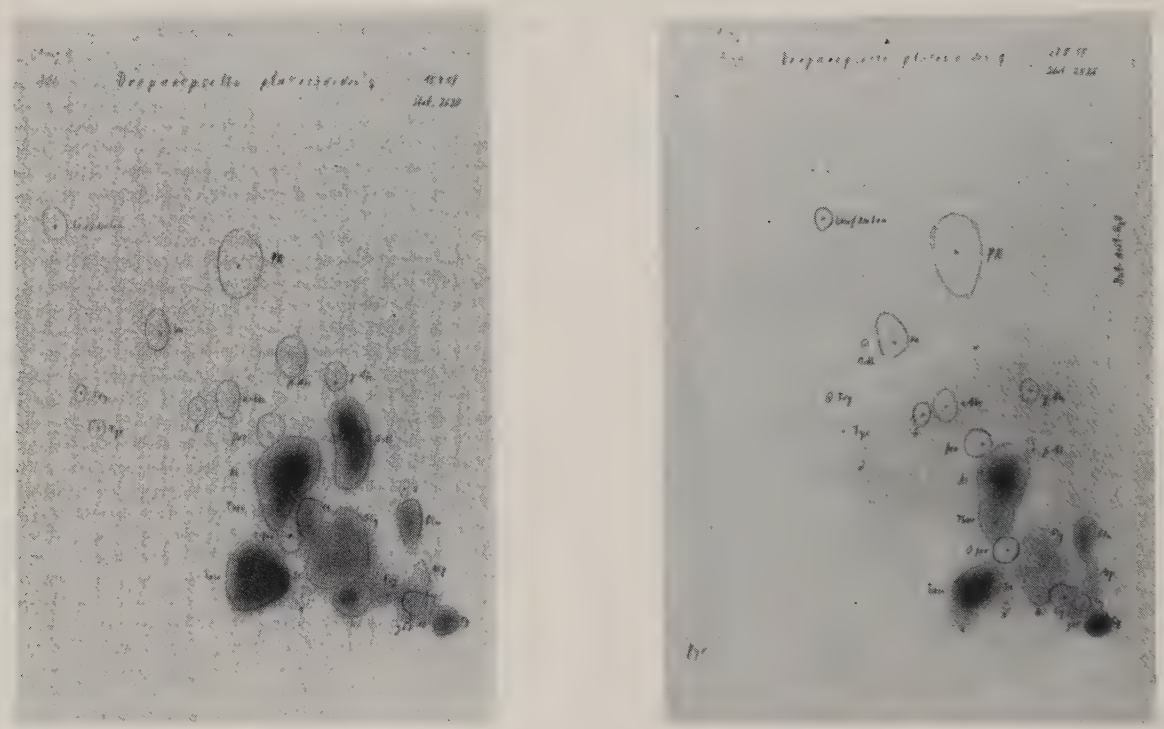
It is evident that the redfish caught at several stations differ significantly in the winter catches by the amounts of alanine-threonine (at the 0·1 % level) and of total N (at the 5 % level) and in the summer catches by the amounts of glycine-serine and of alanine-threonine (5 % level of significance).

These results have been confirmed by the comparisons of every two stations by means of the distribution of *t*, where the standard deviations are composed of both biological variability and methodical errors according to $s^2 = s_1^2 + \frac{s_2^2}{K}$. It is proved, however, that not all the stations show significant differences. This is easily understood since the factors influencing the pattern of the free amino acids in the fish muscle must not be different at all the stations.

Significant differences in *Sebastes mentella* between the various stations are found in the values for the ninhydrin positive substances in summer and for glutamic acid in winter (Table 4).

Cod caught at two stations in winter and at two stations in summer shows the results given in Table 5 without being divided into seasonal catches. A high significance is found only in glutamic acid. It is not possible, however, to decide whether the varying values of glutamic acid are to be attributed to the differences between the stations or are caused by seasonal influences. That these latter may take place is shown for redfish in Table 6.

*) Statistical methods from Koller, 1955.



A. B.

Figure 8. Paper chromatograms of free amino acids in muscles of *Drepanopsetta platessoides* caught at two different stations. A = high amount of β-alanine (βAl). B = small amount of β-alanine.

Table 4. Comparison of the concentrations *within* and *between* the stations

Sebastes mentella, winter: 3 stations; summer: 4 stations

Substance	Winter			Summer		
	Number of fish	F distribution	Level of significance	Number of fish	F distribution	Level of significance
n.p.s.	7	1·9	–	9	5·84	5 %
N	8	0·4	–	9	0·01	–
gly-se	6	5·37	–	9	0·4	–
glut	6	9·73	5 %	9	2·17	–
al-thr	6	7·44	–	9	2·67	–

Abbreviations:

n.p.s. = ninhydrin positive substances
gly-se = glycine-serine
glut = glutamic acid
al-thr = alanine-threonine
The concentrations of n.p.s. and amino acids are expressed in mg/100 mg total extract N
N = total extract nitrogen, mg/100 g fresh muscle

The results obtained by the statistical calculations show that in spite of relatively large errors caused by the applied methods and in spite of the sometimes great biological variability, significant differences in the content of nitrogen and free amino acids are evident between the fishes caught at varying stations. The results shown in Figures 2—7 have been, at least in part, confirmed statistically. The values of proline and histidine were not calculated as above since they are only estimations. The differences regarding proline, histidine, and, also, β-alanine and arginine seem to be, however, so great in the studied species caught at various places, that the existence of the true divergences may be assumed.

Table 5. Comparison of the concentrations *within* and *between* the stations

Gadus callarias, 4 stations

Substance	Number of fish	F distribution	Level of significance
n.p.s.	13	3·03	–
N	13	1·75	–
gly-se	13	1·85	–
glut	12	24·65	0·1 %
al-thr	13	0·65	–

Abbreviations: see Table 4.

Discussion

There is so far a certain parallel to the results of Florkin and B. Ranke in that any factors whatever — these authors worked with varying salinity and temperature of the water — cause changes in the concentrations of free amino acids in the muscle. From his experiments on *Eriocheir sinensis,* Florkin drew the conclusion that there are various conditions of the intracellular system of free amino acids. This is confirmed by the analysis of fish in their natural environment dealt with in this paper.

The fact that particularly proline is found in greatly varying amounts in different localities suggests that the decisive factors are to be sought in the surrounding waters. The hydrographical conditions at the various stations differed, however, only very slightly and did not correspond to the variations of the amino acids. The depth of the hauls seems also to be unimportant. It is possible that nutrition plays a certain role. According to Farris (1958) nutritional differences do influence the composition of the pool

Table 6. Seasonal differences in the composition of the pool of free amino acids in the muscle of fish

Substance	Season	$\bar{x}$	s	Number of fish	t	Level of significance
Sebastes marinus L.						
n.p.s.	winter	156	40·9	14	0·2	–
	summer	152	49·3	12		
N	winter	158	30·9	26	2·13	5 %
	summer	185	46·1	12		
gly-se	winter	15·7	5·39	14	1·68	–
	summer	20·5	8·88	12		
glut	winter	1·86	1·52	14	0·1	–
	summer	1·91	0·94	12		
al-thr	winter	5·54	3·83	14	1·51	–
	summer	7·72	3·45	12		
Sebastes mentella Travin						
n.p.s.	winter	92	53·8	7	0·3	–
	summer	99	60·3	9		
N	winter	191	31	8	0·1	–
	summer	192	13·8	9		
gly-se	winter	11·8	3·16	6	0·4	–
	summer	12·9	5·19	9		
glut	winter	4·03	2·25	6	2·48	5 %
	summer	1·99	0·88	9		
al-thr	winter	9·67	4·35	6	2·25	5 %
	summer	5·78	2·37	9		

Abbreviations: see also Table 4).
$\bar{x}$ = mean — s = standard deviation — t = t of t-distribution.

of the free amino acids in fish muscle. Experiments are intended to throw light upon the problem as to which extent spawning influences the system of the free amino acids in the muscle. Jones (1954) observed considerable variations of the concentrations of some amino acids in the yearly cycle of cod.

Eva Dannevig (1956) who used, however, another method also noticed variations in the pattern of the ninhydrin positive substances in cod from several localities. She attributes this to the occurrence of several local races. I think it is somewhat daring to assume that the fishes dealt with in my report, e. g. redfish, belong to different local races.

The question of the causes of the divergences shown here must for the present remain unanswered.

The results hitherto reached prove that it is not right to make a biochemical investigation of a given species of fish with individuals which stem from only one fishing locality and to generalize the finding for this species. It must once more be emphasized, as did Love (1957), that the fishes to be analysed have to be specified indicating not only species, but also fishing place and date of capture.

Summary

On the expeditions of the R/V "Anton Dohrn" within the Polar Front Programme of the International Geophysical Year, samples of muscle tissue were collected from freshly caught oceanic fish and the pattern of the free amino acids was studied by means of paper chromatography.

The individual fish of a given species caught in several localities show a greater variability regarding certain amino acids than the fish caught in the same haul. This was proved statistically.

The following fish species were studied:—

Sebastes marinus L. *Sebastes mentella* Travin *Gadus callarias* L. *Trigla gurnardus* L. *Drepanopsetta platessoides* Fabr. = *Hippoglossoides platessoides* Fabricii *Brosmius brosme* Asc. = *Brosme brosme* Müller.

Significant differences between the samples from the various fishing places were found in: ninhydrin positive substances (amino acids, taurine and peptides), total nitrogen, glycine-serine, alanine-threonine, glutamic acid and probably in proline, β-alanine, histidine, and arginine.

Seasonal variations in the concentrations of some amino acids were found at the 5 % level of significance in redfish.

Acknowledgement

I wish to express my gratitude to the "Deutsche Forschungsgemeinschaft" for at grant.

The analyses were carried out in the laboratories of the Fischereibiologische Abteilung, Institut für Meereskunde der Universität Kiel. I am greatly indebted to Prof. Dr. Kändler for his kind hospitality and aid.

Finally I owe sincere thanks to Mr. Marschall, Bremerhaven for his help on board the ship.

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III. PLANKTON

5.

Some Remarks on the Distribution of Zooplankton, Fish Eggs and Larvae in the Norwegian Sea in 1958*)

By
Kr. Fr. Wiborg

Summary

The variations in zooplankton volume at fixed stations along the coast of Norway, western Spitsbergen, and at St. "M" in the Norwegian Sea have been studied during 1957 and 1958. In 1957 the plankton was on the whole less abundant than in the previous year, and at Skrova the spring maximum also occurred one month later than in 1956.

In 1958, the plankton volumes were again larger, except at St. "M". Peaks in volume were observed at Skrova in May and August, at Skarsvåg near North Cape, and Kongsfjord, western Spitsbergen, in July and September.

Salps were abundant at Skrova and Skarsvåg in October 1958.

Zooplankton was sampled in vertical hauls with a one-metre net in the Norwegian Sea and adjacent areas in May-June 1958. The plankton was most abundant in the cold, north-western parts of the sea, and off the coast of northern Norway.

During most part of the cruise a shallow layer was recorded on an echo-sounder. The recordings were quantitatively charted. In relation to the quantitative distribution of zooplankton various discrepancies were found. By comparing the distribution of various plankton organisms with the echo recordings, it was found that the echoes probably were caused by fish fry and euphausiids, some possibly also by appendicularians and medusae.

The average stage distribution of *Calanus finmarchicus* during the cruise in 1958 gives a picture very similar to that of the isotherms at 20 m.

The size frequencies of cod and haddock eggs, sampled in coastal and offshore waters of north-western Norway have been studied. Within the same species, variations in the mean size of the eggs have been observed, as well as differences in the mean size between eggs of cod and haddock. During the years 1951—58 the cod eggs at Skrova in the Lofoten area decreased in mean size during the spawning season. Following Heincke and Ehrenbaum (1900), the size variations are thought to be partly related to decreasing egg size in the individual fish from the beginning to the end of the same season.

In 1957 cod eggs and larvae were relatively scarce at Skrova, but in 1958 they were abundant.

Length measurements of cod fry taken in a high-speed net at varying depths near Skrova in June 1957 indicate that the smaller fry as a rule keep to greater depths.

In April 1957 fish eggs, probably of haddock, were moderately abundant along the edge off Lofoten and Vesterålen.

In April—May 1958 haddock eggs and larvae were mainly found east of Shetland and off Vesterålen, some also west of the Halten Bank.

Cusk (or tusk, *Brosmius brosme*) eggs were distributed within the 400 m contour from Shetland to the north of Andenes.

Saithe larvae were mainly taken on Tampen, off Stadt, and on the Halten Bank.

In May 1957 herring larvae were taken in moderate numbers on the coast banks from Ona to Træna, a few also farther north. In June larger herring fry were relatively numerous in the same areas, in the Vestfjord, and on the coastal banks farther north. The mean length of this herring decreased southwards from Vesterålen to Möre.

In April—May 1958 small herring larvae were abundant north-east of Shetland, off Stadt, and on the Halten Bank. From the end of May to the second half of June larger herring fry (13—42 mm) were taken in numbers from off Vesterålen and southwards.

The abundance of redfish larvae in coastal and offshore waters of northern Norway has been studied, and average figures are available for a series of years. In May—June 1958 redfish larvae were abundant in the same waters, especially outside the edge from Andenes and northwards. The western limit of the distribution of the redfish larvae in the Norwegian Sea coincides with that given by Baranenkova *et al.* (1957).

Length measurements indicate an increase in the mean size of the redfish larvae from about 9 mm at the beginning of June to near 20 mm in coastal areas in August.

*) The paper has been published in full in Rep. Norw. Fish. Invest., *12* (6 & 7). 1960.

6.

Distribution of Plankton in the Norwegian Sea in 1958

By

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For the last ten years the workers of the Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO) have been continuously studying the behaviour and migrations of the Atlanto-Scandian herring. Annual observations on the composition and quantities of plankton also took place in connexion with the study of the feeding migrations of herring.

Investigations aimed at finding regular patterns of plankton distribution help to understand some peculiar aspects of the biology and life cycle of the herring and to identify more exactly the periods and routes of their migrations.

Observations on the distribution of plankton in the Norwegian Sea were continued in 1958. During spring and autumn the studies were conducted in accordance with the IGY programme, and during summer, in connexion with the PINRO programme of herring investigations, co-ordinated with Norway and Iceland.

In 1958, Soviet scientists have collected and treated about 3,300 plankton samples and have prepared the charts of quantitative distribution of plankton. A considerable part of these plankton samples were taken in fulfilment of the IGY programme.

When comparing the data obtained with the results of previous years the conclusions below can be made.

Contrary to the previous years, the spring/summer season of 1958 was poor with regard to the development of phytoplankton. During the spring investigations a considerable decrease in the quantity of phytoplankton taken from the shores was observed in the Norwegian coastal area and around Iceland. In the waters of the East Icelandic Current phytoplankton was practically absent.

Halosphaera viridis was abundant in the southern Norwegian Sea near the border to the North Sea, and *Phaeocystis* was dominant at the Faroes and the Lofotens.

In summer (June/July), the warm waters of the Norwegian Current were dominated by *Rhizosolenia styliformis*.

In the waters of the East Icelandic Current the development of phytoplankton started in June (*Phaeocystis* and *Thalassiothrix*) and continued in July/August (*Rhizosolenia hebetata*).

In October, Peridineae, *Ceratium tripos*, and *C. macroceros* entered the eastern Norwegian Sea; at the same time phytoplankton disappeared from the waters of the East Icelandic Current.

During June/July, *Thalassiothrix longissima* was developing in the cold waters to the north-west of the Mona Sill.

The year 1958 was especially characterized by poor and retarded development of diatoms and Peridineae. *Phaeocystis* was not so abundant as in the previous years.

Although the quantitative development of phytoplankton was slow, its duration has apparently had a favourable effect on the development of zooplankton.

Calanus appeared to be particularly abundant in 1958.

Calanus finmarchicus dominated in the eastern Norwegian Sea, south of the Mona Sill, and *Calanus hyperboreus* was frequently found in the north.

The biomass of *Calanus* in the 100-0 m layer in the waters of the Norwegian Current at the end of March and in April was 200—500 mg/m^3 (see Fig. 1).

In the waters of the East Icelandic Current where reproduction of *Calanus* had not yet started in April, the amount of plankton in the upper layers was less than 50 mg/m^3. In June, when reproduction of *Calanus* was in full swing and when concentrations of Crustacea were found in the surface layers, the plankton biomass reached a value of 200—500 mg/m^3.

In June, plankton was abundant in the waters of the Norwegian Current (800—2,000 mg/m^3) and in the area bordering the East Icelandic Current (over 3,000 mg/m^3).

In the eastern part of the Norwegian Sea, near the

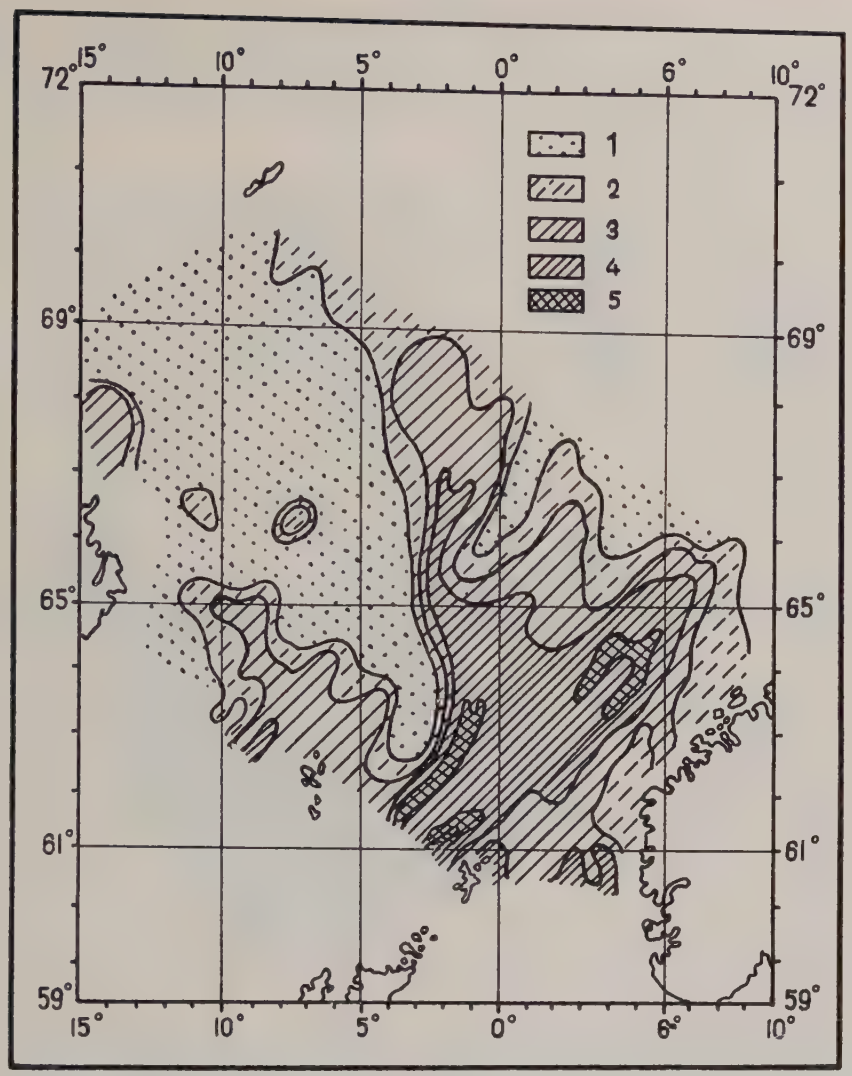

Figure 1. Quantitative distribution of plankton in the 100—0 m layer in March/April 1958.
1, up to 50 mg/m³; 2, from 50 to 100 mg/m³; 3, from 100 to 200 mg/m³; 4, from 200 to 500 mg/m³; 5, over 500 mg/m³.

boundary of the Barents Sea, the biomass of *Calanus* in June often reached 5,000 mg/m³, while the maximum figure was 9,800 mg/m³.

In the cold, north-western waters *Calanus hyperboreus* ascending to the surface layers for reproduction, was dominant.

During July, nauplii and young *Calanus finmarchicus* reappeared in the southern Norwegian Sea. Smaller young specimens of *Calanus finmarchicus* occurred also during summer to the north of this area in the eastern branch of the Norwegian Current.

By autumn, the plankton biomass had also increased sharply in the western part of the Norwegian Sea. For instance, *Calanus* reached copepodite stage V by September/October and dominated the plankton showing a biomass value of 500—800 mg/m³ (see Fig. 2).

In autumn, plankton was abundant in the eastern branch of the Norwegian Current but besides *Calanus finmarchicus* it contained a great number of other neritic and warm-water organisms.

Young euphausiids and Hyperiidea, medusae, and salps especially augmented the biomass of plankton.

The black portion (8) of Figure 2 shows the area near the Norwegian coast and that to the north-east of the Faroe-Shetland Channel where *Salpa fusiformis* was dominant.

In 1958, unlike the previous years (and especially 1954), the medusae *Aglantha digitale* were markedly less well represented. Most often they were observed

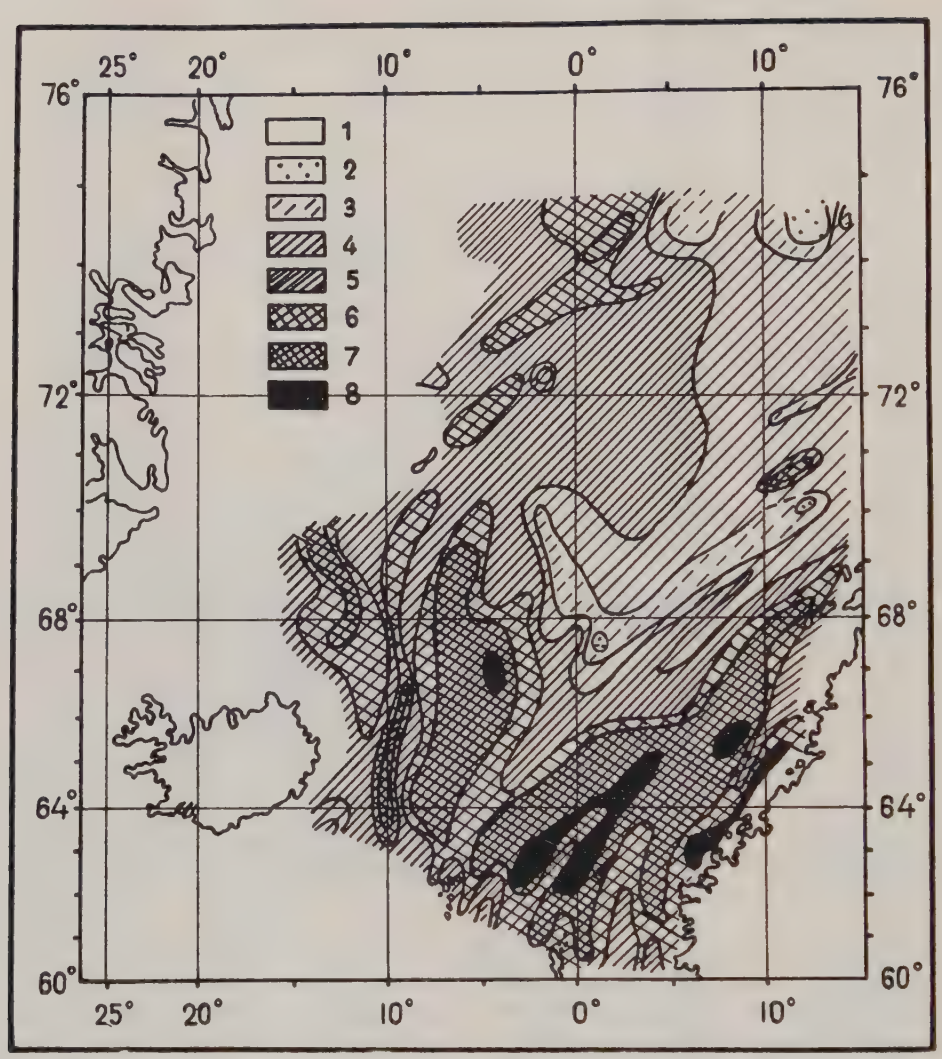

Figure 2. Quantitative distribution of plankton in the 100—0 m layer in September/October 1958.
1, no investigations; 2, up to 50 mg/m³; 3, from 50 to 100 mg/m³; 4, from 100 to 200 mg/m³; 5, from 200 to 500 mg/m³; 6, from 500 to 800 mg/m³; 7, from 800 to 2,000 mg/m³; 8, over 2,000 mg/m³.

in the western branch of the Norwegian Current (0°—6°E), but even there they did not spread farther than 71°N.

During spring 1958, the warm-water organisms (*Collozoum* sp., *Tomopteris* sp., and *Limacina retroversa*) were not numerous and were found in the western part of the Norwegian Sea.

In autumn (September/October), such warmwater species as *Salpa fusiformis, Doliolum* sp., *Pleuromamma robusta, Anomalocera patersoni,* and others were found in great numbers in the western branch of the Norwegian Current.

Also in autumn, great quantities of plankton serving as food for herring (*Calanus finmarchicus* in IV—V copepodite stages) were found in the western part of the Norwegian Sea.

Observations on the development of plankton in the Norwegian Sea during 1958 allowed us to conclude that the somewhat slow development of the vernal biological processes and the prolongation of copepodite stages III—IV—V of *Calanus finmarchicus* in the surface layers of the central and eastern regions of the sea have provided favourable feeding conditions for herring during the spring/summer period of 1958

7.

The Plankton of the Iceland-Faroe Ridge in 1958

By

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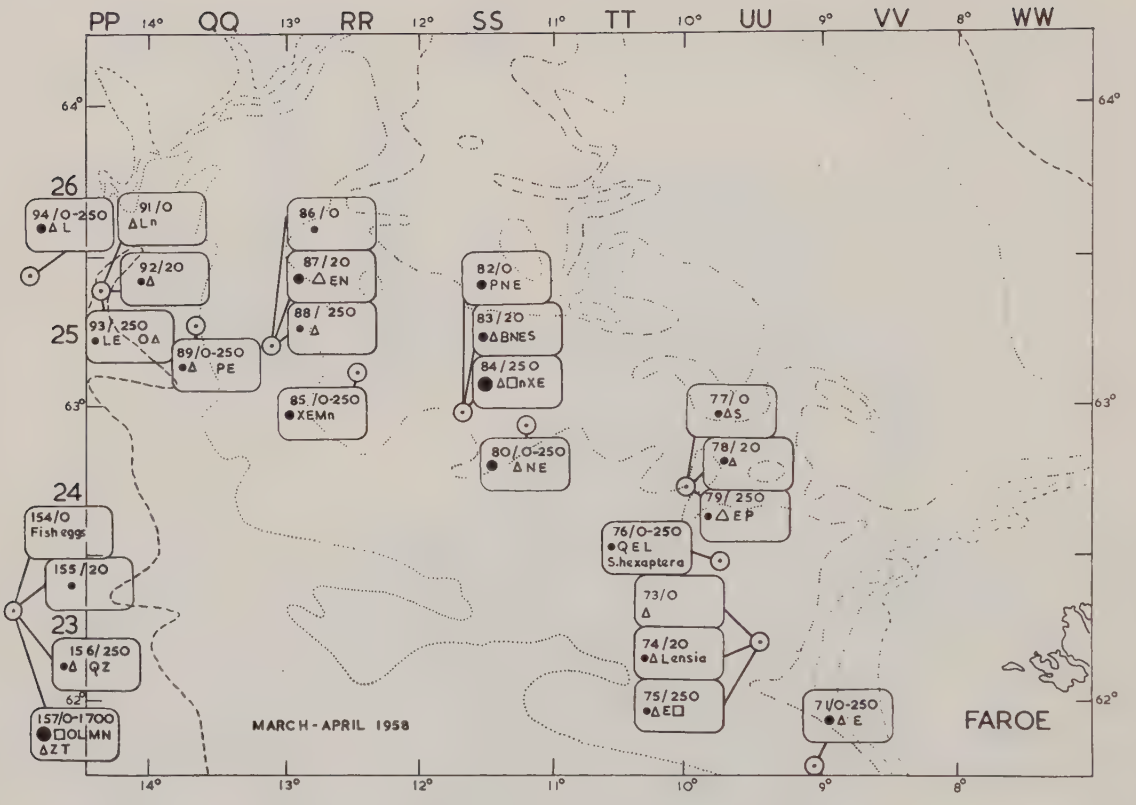
The Scottish research ship "Explorer" worked in e region of the Iceland-Faroe Ridge in March/ pril, August, and September 1958. Plankton samples ere collected with 1 metre non-closing silk nets, 26 eshes per inch, either as oblique hauls from 250 etres to the surface or towed horizontally for 15 inutes at the surface, at 20 metres and at 250 etres depth. Over the shelf, in water shallower than 00 metres, the depth of the nets was restricted to 00 metres (haul 599). The station positions with aul numbers and the depth of the nets are indicated n the charts and are similar for the spring and utumn cruises except that samples were taken in ring in the deep water south-west of the Ridge and autumn a station was worked about the centre of ie north-east edge of the Ridge. The bathymetrical ntours are taken from Steele (1958). The August llections were taken as part of a different pro- amme and were all west of the Ridge but are in- uded in this paper to complement the main part — comparison between the spring and the autumn una of the Ridge.

During spring the planktonic fauna of the Ridge as not abundant. *Calanus finmarchicus* was gener- ly scarce, and the presence of *Pleuromamma robu- a, Physophora,* and *Sagitta elegans arctica* at sever- stations indicates that this fauna was of boreal ther than Atlantic origin. This does not mean that ie water over the Ridge was outflowing from the orwegian Sea or a much richer plankton would have en expected, but merely that it had been in the ea over the winter and was little influenced by rth-flowing water that had recently been in the armer areas of the Central Atlantic.

Nevertheless, in spite of this poor fauna, there are ight but revealing differences along the length of the survey. Just off the edge of the Ridge, in the deeper water north-west of Faroe (hauls 73—76), there is slight evidence of Atlantic inflow in the presence of the siphonophore *Lensia conoidea* at 20 m (haul 74) and *Sagitta hexaptera* and the squid *Trachelotheuthis riseii* in the oblique haul (No. 76). At about the centre of the Ridge (hauls 82—84) the plankton was richer and more distinctly boreal than elsewhere, with *Calanus* abundant at 250 m and moderately abundant at 20 m and at the surface, and with *Sagitta elegans arctica, Beroe* and *Pareuchaeta norvegica* also forming an important fraction of the sample. This richer fauna had a tendency to extend to a slight degree to the north-west but not to the south-east of this position. It is probably associated with a slight bottom outflow from the Norwegian Sea in the neighbourhood (as found by Steele, 1958) and a slow turbulent upwelling had dispersed the richer fauna throughout the depth. Further to the north-west the fauna became poor again, but once more with the merest trace of Atlantic influence in the deep tongue west of the Ridge and just south of the Icelandic Plateau, shown by the presence there of *Eucalanus elongatus* (haul 93).

By September the conditions had changed radically and the whole of the area surveyed was flooded with Atlantic water, except at the station on the north-east edge of the Ridge (hauls 810—812) where a considerable proportion of boreal species was still present. As in March there were slight but revealing faunistic differences from one end of the ridge to the other. At the south-east end, off the edge of the Faroe Plateau, were found the salp *Iasis zonaria* (haul 815) and the copepod *Eucalanus crassus* (haul 816) indicating a link between these and the fauna west of Scotland (see *Annales Biologiques* for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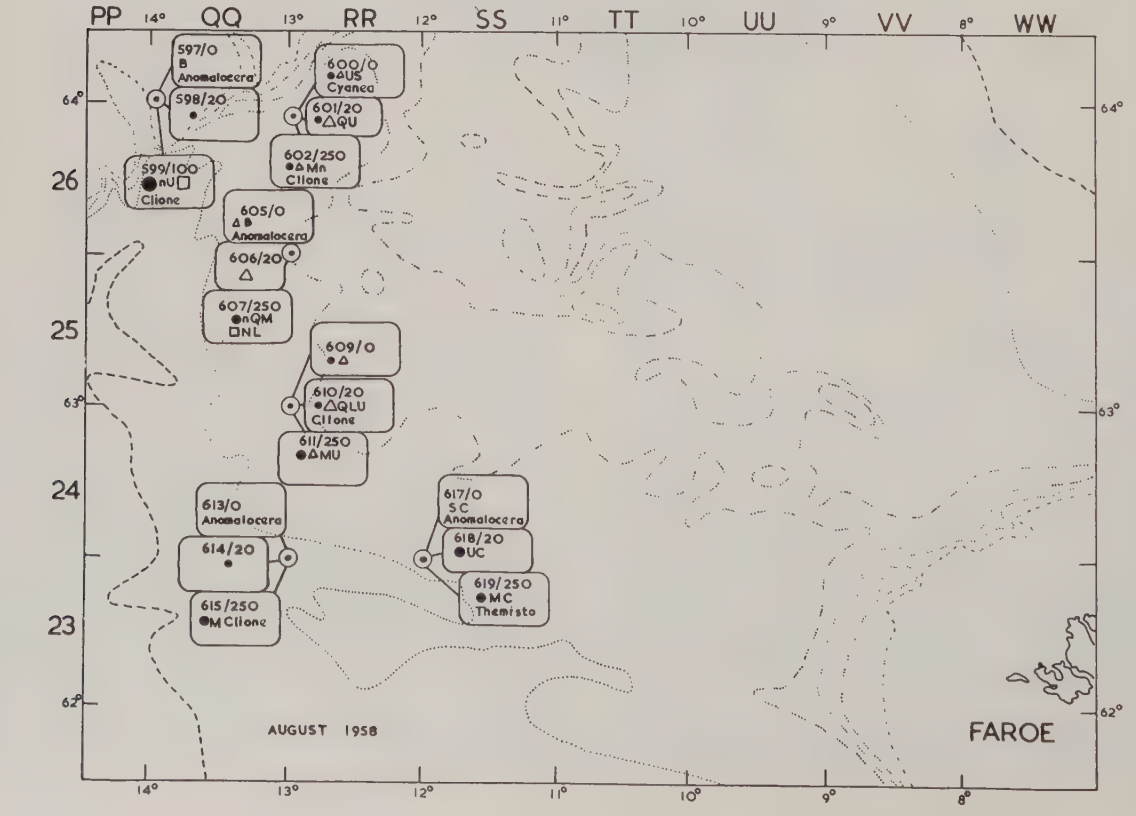
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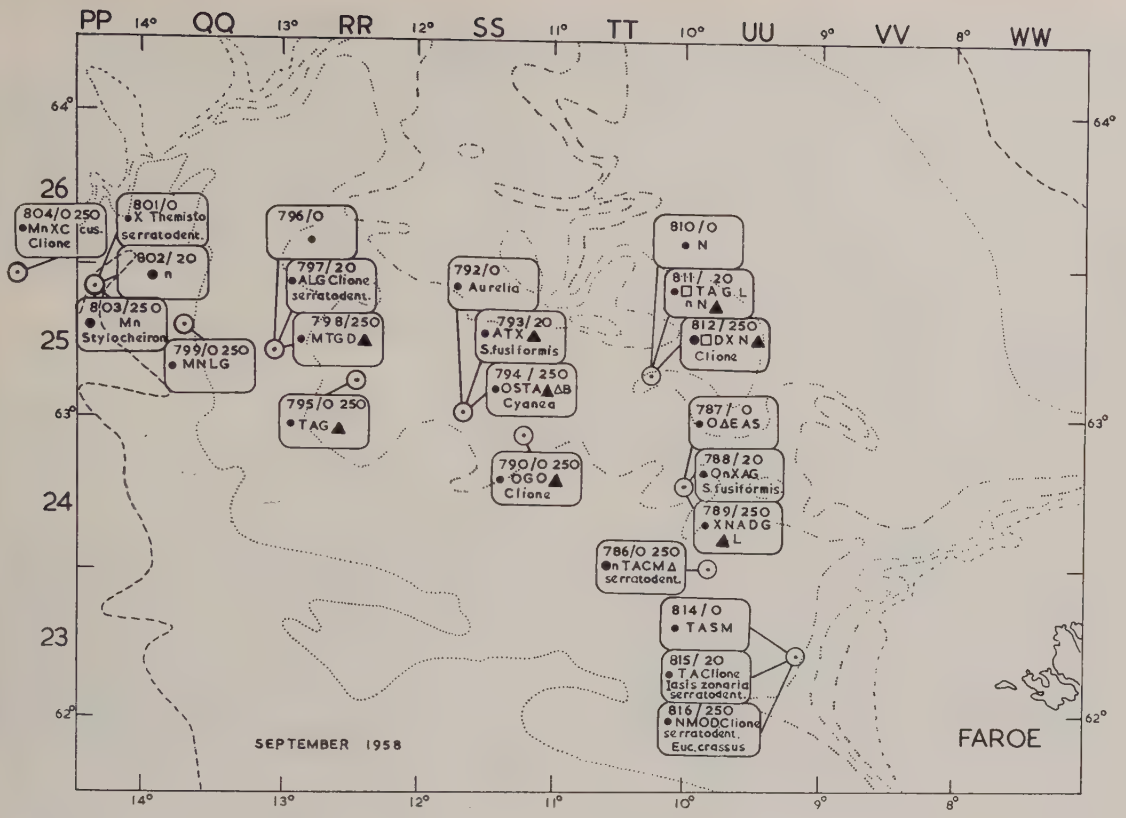

Key to Symbols used on the Charts.

⊙	Position of station
	Haul No./Depth of sample
•●●	*Calanus finmarchicus;* present, common, abundant.
□	*Calanus hyperboreus* or *Metridia longa*
○	*Rhincalanus nasutus* or *Eucalanus elongatus*
Euc. crassus	*Eucalanus crassus*
n	*Pareuchaeta norvegica*
X	*Pleuromamma robusta*
N	*Meganyctiphanes norvegica*
L	*Thysanoessa longicaudata*
E	*Sagitta elegans* var. *arctica*
M	*Sagitta maxima*
serratodent.	*Sagitta serratodentata*
Clione	*Clione limacina*
C	*Clio pyramidata*
cus	*Clio cuspidata*
Q	Planktonic squids
B	*Beroe*
G	*Agalma elegans*
▲	*Lensia conoidea*
S	*Sulculeolaria biloba*
D	*Dimophyes arctica*
P	*Physophora*
U	*Laodicea undulata*
△	*Aglantha digitata*
A	*Arachnactes* larvae
T	*Thalassicolla*

1958) where there was a distinct Lusitanian plankton. *Salpa fusiformis* was found only in the central region of the Ridge (hauls 788 and 793) indicating a link there with the North Atlantic Central water, while to the north-west *Clio cuspidata* (haul 804) shows the presence of Atlantic water almost at the edge of the Icelandic Shelf. *Arachnactes* larvae and the radiolarian *Thalassicolla* were found except at the north-west end, the siphonophore *Agalma elegans* except at the south-east end, *Clione limacina* was found throughout, and *Lensia conoidea* only in the central portion.

This arrangement indicates that this flow was not forming a complete eddy to the south-west of the Iceland-Faroe Ridge as depicted by Einarsson (1954), as to do so would mean a fairly homogeneous plankton content along the Ridge. It does, in fact, suggest that water from a southern origin was crossing at the south-east end of the Ridge, west and north-west of Faroe, to continue into the southern part of the Norwegian Sea, whilst the northern end was being affected by Atlantic water from the main source east of Reykjanes Ridge. In the centre the concentration of Atlantic species would suggest the edge of an eddy formation enfringed there without much overflow, as there were a few but not many Atlantic species at the station east of the Ridge (hauls 810—812). There was no planktonic evidence of overflow of boreal species across the Ridge from the Norwegian Sea in September.

The August sampling did not cover the entire length of the Ridge but nevertheless gives some clue to the conditions leading up to the September plankton distribution. Sampling over the Icelandic Shelf at the north end of the Ridge showed a mixed fauna but with a distinct boreal content especially in the bottom sample (haul 599) taken at 100 m. This contained a rich *Calanus finmarchicus* population, with *Calanus hyperboreus* and *Pareuchaeta norvegica* but also some *Clione* and *Laodicea,* showing that it was not entirely of boreal origin. Further south, unfortunately for this purpose entirely off the shelf, the plankton consisted of indigenous species — a logical development of the fauna of the spring samples — without much influence from either Atlantic or boreal water. *Anomalocera* was present in almost all the surface collections and there was a big increase in the numbers of *Aglantha* and *Laodicea.* Atlantic species were surprisingly rare, a few *Clio pyramidata, Sulculeolaria,* and *Tracheloteuthis* suggest that what slight influence there was came from Atlantic rather than boreal sources. The radical change to the oceanic character of September must have been very rapid indeed.

No collections were taken in 1957 from which a direct comparison of the two years is possible. A general inference from the information available (see *Annales Biologiques*) suggests that 1958 was not a typical year in the Iceland-Faroe region, and that the fauna in 1958 in the area south-west of Iceland, and in the region of the Reykjanes Ridge was distinctly different in 1957 and 1958.

Summary

Sampling by "Explorer" over the Iceland-Faroe Ridge in 1958 shows marked differences in the plankton between spring and autumn. The spring sampling suggests that the fauna had overwintered in the neighbourhood of the Ridge and was only little influenced by north-flowing water from the Central Atlantic. Differences along the length of the Ridge suggest a slight overflow of Atlantic water to the immediate north of the Faroe Plateau and a slight incursion into the deep tongue to the west of the Ridge just south of the Icelandic Shelf. A somewhat richer boreal fauna in the centre of the Ridge suggests a slight bottom outflow from the Norwegian Sea associated with a turbulent upwelling.

The autumn sampling showed that the whole area of the Ridge was flooded by Atlantic fauna, but that there was still a considerable proportion of boreal species just to the north-east of the Ridge. As in the spring there were small but revealing differences from one end of the Ridge to the other. The fauna off the edge of the Faroe Plateau suggests a linkage with the Lusitanian fauna west of the British Isles. The fauna of the northern part of the Ridge suggests that it was affected by water from the North Atlantic Central water, from east of the Reykjanes Ridge, whilst the central part coincided with an eddy formation without much overflow into the Norwegian Sea.

Sampling in August, whilst not actually covering the area of the Ridge, suggests that the changeover from the spring to the autumn conditions occurred between August and September.

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8.

Distribution of Plankton in the North Atlantic in Spring and Autumn 1958

By

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Planktonic studies in line with the IGY programme for 1957–58 have been carried out on board the R/V "M. Lomonosov" in the North Atlantic during March–April and October–November–December 1958. Investigations covered the area from the coasts of Spain to Newfoundland (Fig. 1).

Zooplankton was sampled with a No. 38 (38 threads per cm) Juday net of 36 cm diameter from the following depths: 500–200 m; 200–100 m; 100–50 m; 50–25 m; 25–10 m; 10–0 m, and in addition, at some stations with No. 14 (14 threads per cm) Juday net of 80 cm diameter.

Phytoplankton was sampled horizontally with Nansen bottles at 0·5 m, 10 m, 25 m, and 100 m.

Preliminary treatment of plankton consisted in the determination of the volume of seston by the method of water displacement.

Before such determination, salps, Hydromedusae, and Ctenophora were removed from the samples.

The quantity of *Calanus finmarchicus* in the samples was calculated in full and converted to biomass values.

While determining the qualitative composition of zooplankton the main attention was given to the order Copepoda.

In spite of a relatively good knowledge of the Atlantic Ocean, plankton in certain areas was found to be insufficiently studied.

Hentschel (1942), while compiling the biological map of the Atlantic Ocean, marked off "the Northern intermediate area" in the North Atlantic; however, having but few planktonic data, he could not outline the exact borders of this area.

The region covered by our investigations to a considerable extent coincided with this area in the east and included part of the region in the west that was distinguished by Hentschel as the "boreal area".

The quantitative composition of zooplankton in the investigated area was marked by its diversity. According to the results of the preliminary processing of the data obtained, about 150 species were ascertained.

The following Copepoda species were found most frequently in spring: *Calanus finmarchicus, Calanus helgolandicus, Nanocalanus minor, Neocalanus gracilis, Eucalanus elongatus, Rhincalanus nasutus, Mecynocera clausi, Calocalanus tenuis, C. styliremis, Clausocalanus arcuicornis, Ctenocalanus vanus, Aetideus armatus, Euchirella rostrata, Euchaeta acuta, Pareuchaeta norvegica, Pleuromamma robusta, P. borealis, P. gracilis, P. abdominalis, P. xiphias, Metridia lucens, Lucicutia flavicornis, Oithona similis, O. spinirostris, Corycaeus* spp., and *Sapphirina* spp.

Eucalanus elongatus, Ctenocalanus vanus, and *Euchirella rostrata* occurred in autumn more rarely than in spring, while *Calanus helgolandicus* was almost never observed in autumn.

In comparison with spring, more important in autumn were *Calanus tenuicornis, Paracalanus parvus, Haloptilus longicornis, Clytemnestra* spp., and *Copilia* spp.

The boreal species developed to the north of the 10°C isotherm at the surface, and the subtropical and tropical forms to the south of it. A transition zone of a few score of miles long was observed between the areas of distribution of boreal and southern warm-water species, where representatives of both faunae were found simultaneously.

Let us consider the distribution of some, most numerous, planktonic organisms representing important food organisms for fishes, whose distribution can make it easier to understand the régime of the given area.

No essential difference was observed in the spring and autumn distribution in the 500–0 m layer in the distribution of the main representative of boreal

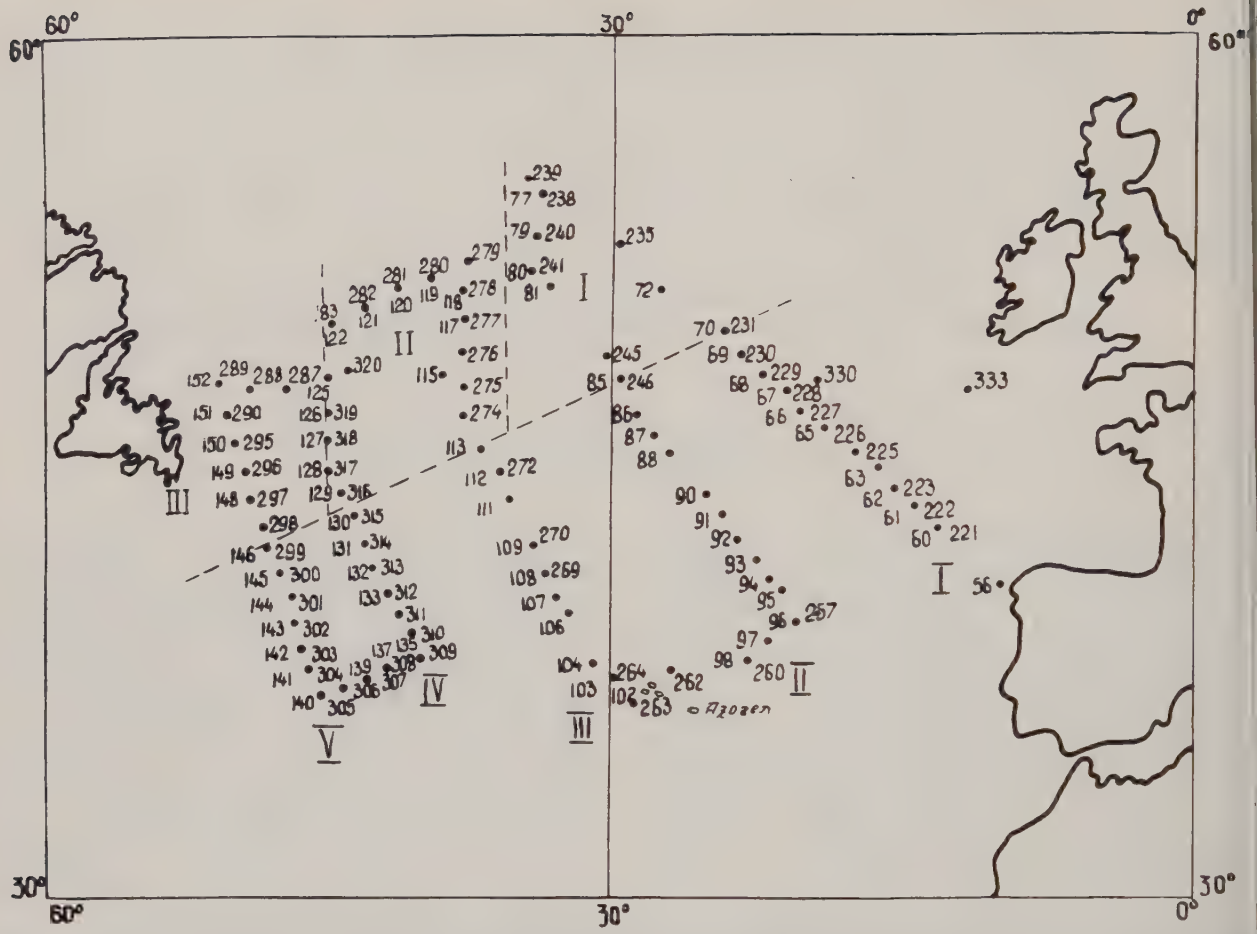


Figure 1. Chart of the stations worked during the spring and autumn oceanographic survey with the R/V "M. Lomonosov". Stations 56—152 = Spring survey. Stations 221—289 = Autumn survey. The Roman numerals above the dotted line denote areas, those below the line are the section.

fauna of the investigated area — *Calanus finmarchicus* (Fig. 2.). The southern border of the distribution of *Calanus* was the same in both seasons. However, there was a considerable difference in the vertical distribution. During the spring, the population of *C. finmarchicus* in the area of sections 1 and 2 (Area I, Fig. 1) remained in the layer 500—200 m, and did not ascend to the upper layers even at night. Farther westward (Areas II and III, Fig. 1) the population of *Calanus* occurred in the water layer from 500 m to the surface. On the other hand, in autumn *C. finmarchicus* was found in the layer 500—200 m both in Areas I and II, and only in the shallow area of Newfoundland Bank was it observed from the bottom to the surface.

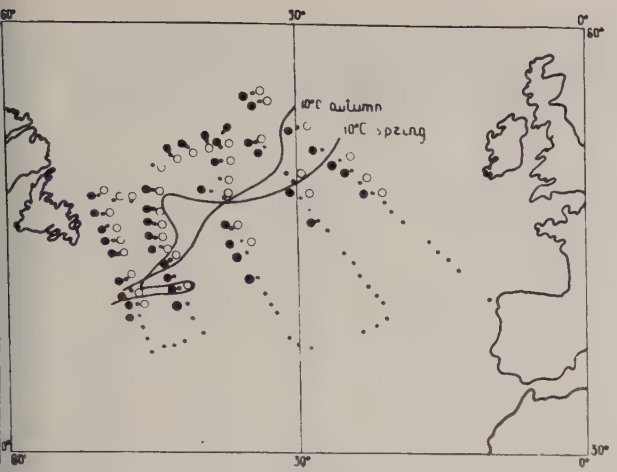
The greatest quantities of *C. finmarchicus* were found in plankton to the north of the 10°C isotherm at the surface, while to the south of it, *Calanus* was found in far lesser numbers.

The area of distribution of *C. helgolandicus* in the North Atlantic has not been established for a long time.

During recent years, V. A. Yashnov (1958) and K. A. Brodsky (1959) have outlined the limits of distribution of various species of *Calanus*. Our data confirm their assumptions and allow us to define more exactly the area of distribution of *C. finmarchicus* and *C. helgolandicus* in the North Atlantic (Fig. 3).

C. helgolandicus was found during both seasons (in spring and in autumn) to the south of the surface 10°C isotherm.

If in spring it occurred in the plankton at almost every station situated south of this isotherm, in autumn it was present only at four stations. It is true that at many stations of sections II and III plankton was not collected in autumn, but this cannot alter our conclusion on the low autumn frequency of



igure 2. Distribution of *Calanus finmarchicus* in the spring and autumn of 1958.
—— = The surface 10°C isotherm.
● = Spring. ○ = Autumn.

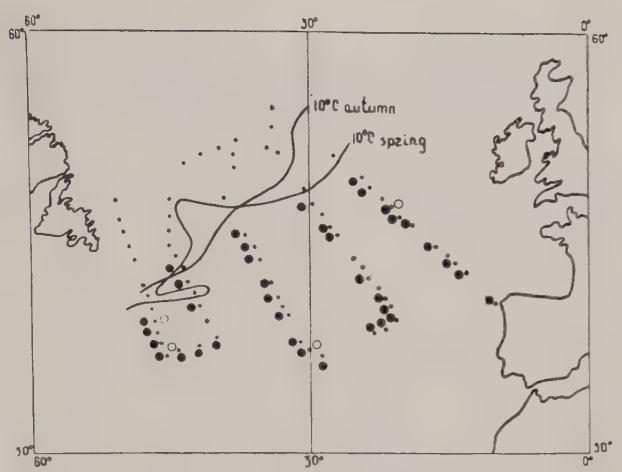


Figure 3. Distribution of *Calanus helgolandicus* in the spring and autumn of 1958. Symbols as for Figure 2.

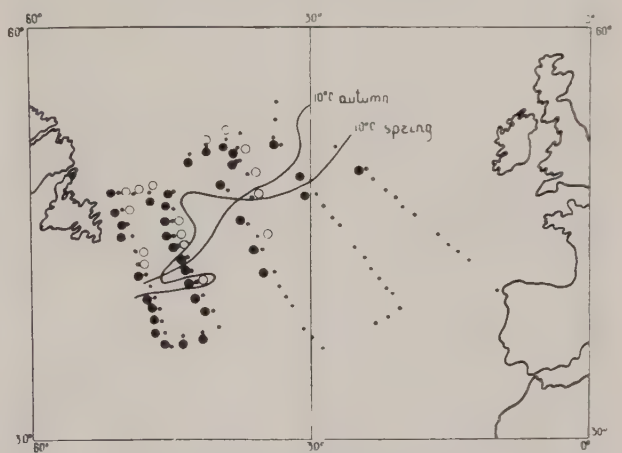


Figure 4. Distribution of *Calanus hyperboreus* in the spring and autumn of 1958. Symbols as for Figure 2.

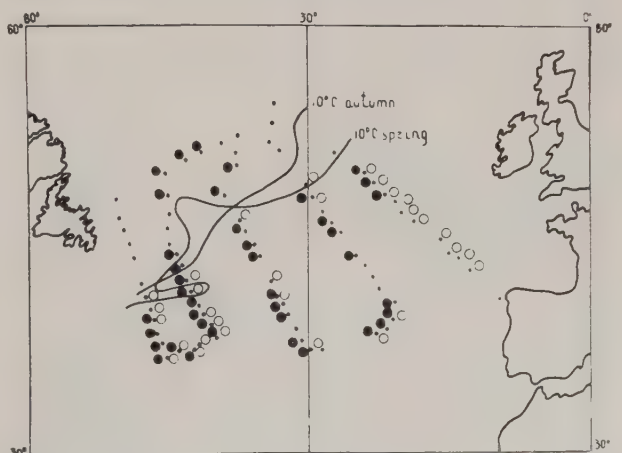


Figure 5. Distribution of salps in the spring and autumn of 1958. Symbols as for Figure 2.

ne distribution of *C. helgolandicus* in the plankton f this area because in section I, where a sufficient mount of plankton has been collected in autumn, *. helgolandicus* was nevertheless found only at one tation out of 10 stations south of the surface 10°C otherm.

In spring, *C. helgolandicus* occurred in the whole vater column from 500 m to the surface; at many tations, the population was represented at all stages f age. The absence of deep-water samples and of ne data collected in summer in this area makes it mpossible so far to explain the material obtained on ne distribution of *C. helgolandicus* in autumn.

Distribution of the arctic representative of plankon — *Calanus hyperboreus* in the 500—0 m layer — vas very similar both in spring and in autumn (Fig.). During both seasons, *Calanus hyperboreus* occurred most frequently in the plankton of sections to III. However, in autumn its spread to the south vas less intensive than in spring.

If *Calanus hyperboreus* can be considered an indiator of the supply of arctic waters to the more outherly areas of the North Atlantic, then comparion of its autumn and spring distribution makes one hink that the spring supply of arctic waters was nore intensive. The same conclusion suggests itself vhen comparing the quantitative distribution of *Canus hyperboreus* in these two seasons.

Warm-water species of salps were found, both in pring and autumn, mainly south of the surface 10°C otherm (Fig. 5), with the exception of stations 117, 20, 121, and 122 where salps were found in spring in mall numbers, the water temperature being 5°C 9°C..

Table 1

Numerical strength and age composition of the *Calanus finmarchicus* population in the North Atlantic in spring and autumn 1958 (average quantity in the 500—0 m layer, caught with a Juday net of 36 cm diameter).

Area	I				II				III			
Season	Spring 13.—20. March		Autumn 21.—26. Oct.		Spring 10.—15. April		Autumn 7.—13. Nov.		Spring 28. April—1. May		Autumn 22.—23. Nov.	
Stages of age	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
I	–	–	0·2	–	8	0·8	0·1	0·06	1,011	30·8	327	19·3
II	–	–	0·6	0·4	23	2·2	0·1	–	468	14·3	322	19·0
III	–	–	0·2	–	25	2·4	0·8	0·1	247	7.5	316	18·7
IV	29	10·9	171	60·0	80	7·7	54	7·3	237	7·2	300	17·8
V	198	74·0	111	38·9	189	18·5	675	92·0	290	8·9	347	20·5
VI(♀)	12	4·5	2	0·7	500	48·8	4	0·54	966	29·6	78	4·6
VI(♂)	28	10·6	–	–	200	19·6	–	–	55	1·7	2	0·1
Total	267	100·0	285	100·0	1,025	100·0	734	100·0	3,274	100·0	1,692	100·0

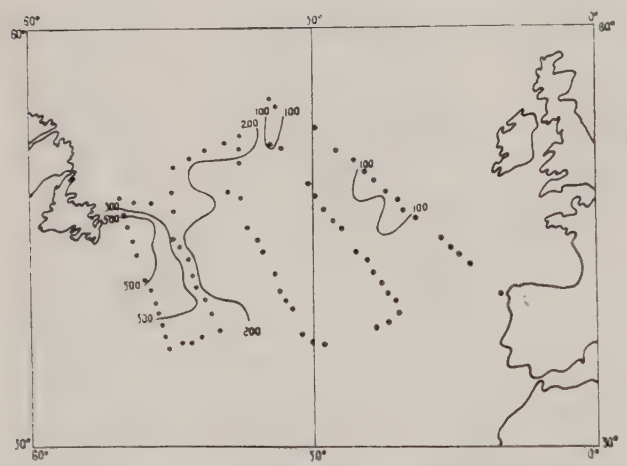


Figure 6. Distribution of plankton in the 200—0 m layer (ml/m³) in spring 1958.

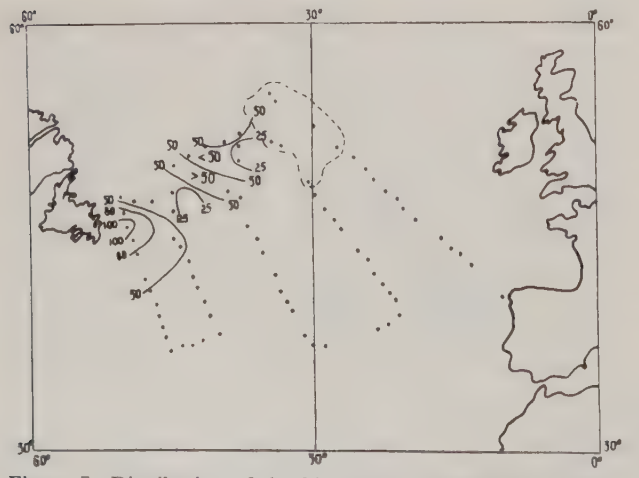


Figure 7. Distribution of the biomass of *Calanus finmarchicus* in the spring of 1958 in the 200—0 m layer (mg/m³).

At stations 117, 120, 121, and 122 individual specimens only of salps were observed; at stations 115, 125, and 129 they were encountered in greater numbers.

South of the 10°C isotherm the main bulk of salps was caught in spring at the stations which apparently had been located within the main stream of the North Atlantic Current (stations 140, 141, 142, 143, 132, 112, 113, 85, 70). South of these waters a considerable aggregation of salps directed eastward was registered in spring at stations 139, 138, 137, 135, 107. These two areas of intensive concentration of salps were divided by waters where salps were either absent or observed as single individuals. Most abundant, both in spring and autumn, was *Salpa fusiformis*.

The quantitative distribution of plankton in spring and autumn 1958 shows that the concentration of plankton in the investigated area of the North Atlantic varied in the 200—0 m layer mainly from 0·1 ml/m³ to 0·3 ml/m³; the Grand Bank of Newfoundland was most abundant in plankton (Fig. 6).

The biomass of *Calanus finmarchicus* in the 200—0 m layer varied in spring from 20 to 100 mg/m³, reaching its maximum in the area of the above bank (Fig. 7). The distribution of the biomass of *Calanus* in autumn in the 200—0 m layer is not shown on the chart because its population at that time remained below 200 m. Study of the composition of the population of *C. finmarchicus* allows us to establish certain differences related apparently not only to seasonal, but to local peculiarities as well. In the boreal area there appeared to be three different regions (Fig. 1) as regards the abundance and age composition of the population (Table 1).

In Area I (shown in Fig. 7 by stippled line) the population of *C. finmarchicus*, both in spring and

autumn, remained in the lower water layers and occurred only in catches taken from 500 to 200 m. The absence of deep-water captures during these seasons prevents us from stating whether *Calanus* was present below 500 m.

There was some difference between the spring and autumn compositions of this population. In spring it was composed of specimens in stages IV, V, and VI, with stage V predominant (74 % of the population). In autumn, an insignificant number of specimens in stages I, II, and III was present in the population; however, most numerous were specimens in stages IV and V, with stage IV predominant.

In spite of the rather high temperature of the upper water layers (7°—9°C), the population remained at the depths from 500 to 200 m and did not ascend to the upper layers even during night time.

The area was characterized by considerable quantities of biogenic substances (phosphates 15—30 mg/m^3, and nitrites 23—28 mg/m^3 in the 100—0 m layer), but no development of phytoplankton was observed. All the stations in the area were homothermic to the depths of 200—300 m which probably unfavourably affected the conditions for the development of phytoplankton in the upper water layers.

At the end of October, judging by the distribution and composition of the population, *Calanus* in this area descended to the deeper layers for the duration of the winter.

It may be noticed that the abundance of *Calanus* in this area both in spring and summer is rather low.

In Area II spring and autumn populations of *Calanus* differed by age composition and by distribution in the water column. In spring, the population was composed of all age-groups, with prevalence of stage VI. *Calanus* could be caught in all layers from 500 m to the surface, that is, the population was ascending after the winter and just entering the period of spring reproduction.

Water temperatures were somewhat lower than in the Area I, but at most stations the beginning of heating of the surface layer and the stratification of the water thickness were observed. The quantity of biogenic elements was somewhat higher (phosphates 23—28 mg/m^3 and nitrates 50—60 mg/m^3), so small quantities of spring diatoms began to develop in the plankton.

During the period of autumn observations, the population of *Calanus* in this area was already found below 200 m. No vertical migrations were observed.

Stage V was prevailing, stages I, II, and III were very poorly represented.

The numerical strength of the population of *C. finmarchicus* in this area was considerably higher than in Area I. In autumn, when the reproduction of *C. finmarchicus* in these two areas had already been completed, the population in the second area proved to be three times more abundant than in the first area. This provides evidence for the supposition that under equal conditions the survival of *Calanus* stocks in winter should be far greater in the second area than in the first one.

The state of the population of *C. finmarchicus* in Area III (Newfoundland Bank) greatly differed from the conditions in the above two areas.

Rather intensive spawning of *C. finmarchicus* in low water temperatures (—0·83 to +1·83) was observed in this area in spring.

In these comparatively shallow depths, the population of *Calanus* was distributed from the bottom to the surface and performed diurnal vertical migrations. The population was dominated by the young. Eggs and nauplii of *Calanus* numbered tens of thousands in one cubic metre of water and were found at all depths, especially in the upper 50 m layer.

The amount of biogenic elements, especially nitrates, in the upper 100 m layer was considerably lower than in the other two areas. At some stations nitrates were not present. This was explained by the consumption of biogenic elements by diatoms that developed here in considerable quantities, causing the "blooming" of the water.

Such a state of the population of *C. finmarchicus* in spring 1958 is usual for the North Atlantic (Nicholls, 1933; Fish, 1936; Kielhorn, 1951). As to the autumn, it has brought some unexpected results. In the third decade of November, the population of *Calanus* was composed of all age-groups, the young dominating, though without prevalence of any particular age stage. The number of eggs and nauplii was not great. So far it remains uncertain if the young belonged to the local population of *Calanus*, or if they were brought from the neighbouring areas from north-west. The latter supposition seems to be more likely.

Considering the distribution of plankton in the north it may be seen that both in spring and autumn its numerical strength was great.

The most abundant area for plankton serving as food for fishes has proved to be that situated to the north of the surface 10°C isotherm.

The abundance of plankton in this area is probably associated with the inflow of arctic waters, rich in nutritious salts, creating favourable conditions for the development of phytoplankton and, subsequently, of zooplankton.

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9.

The Distribution of Microplankton and Organic Matter in the Northern North Atlantic during Late Winter and Late Summer 1958*)

By

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During the IGY, the research vessels "Anton Dohrn" and "Gauss" undertook cruises in the northern North Atlantic in late winter (March/April 1958) and in late summer (August/September 1958). On these occasions water samples were taken in the northern region (Irminger Sea) from all depths in order to determine the quantity of oxidizable organic substances and, in addition, from the surface to 500 m depth for microplankton counts. In the southern region (between 55° and 40°N) only plankton samples were taken.

The counting of such samples usually requires much time. In 1955 a considerable discontinuity in plankton distribution had been observed in this region (Gillbricht, 1959 a). Therefore very accurate determinations of plankton quantities from a few stations only would be of inferior value to less exact data from many stations. For this reason only small quantities of water were examined (0·3 ml highly magnified and 5 ml in less magnification). This direct microscopical determination of the plankton does not consume more time than an indirect chemical one (chlorophyll, etc.) (Gillbricht, 1959 b). The accuracy of a single measurement is of course only slight compared with the traditional method. On the other hand, the averages of a larger number of observations are likely to afford a better estimate of the average conditions in these oceanic regions.

The organic substances were determined by oxidation with permanganate in alkaline solution. This simple method gave better results than I expected (Gillbricht, 1959 c). Duursma (1959) found only slightly higher values by oxidation with sulphuric acid and dichromate. For comparison with other data, rather than stating the quantity of permanganate consumed, the corresponding quantity of carbon was calculated assuming all organic substances to be

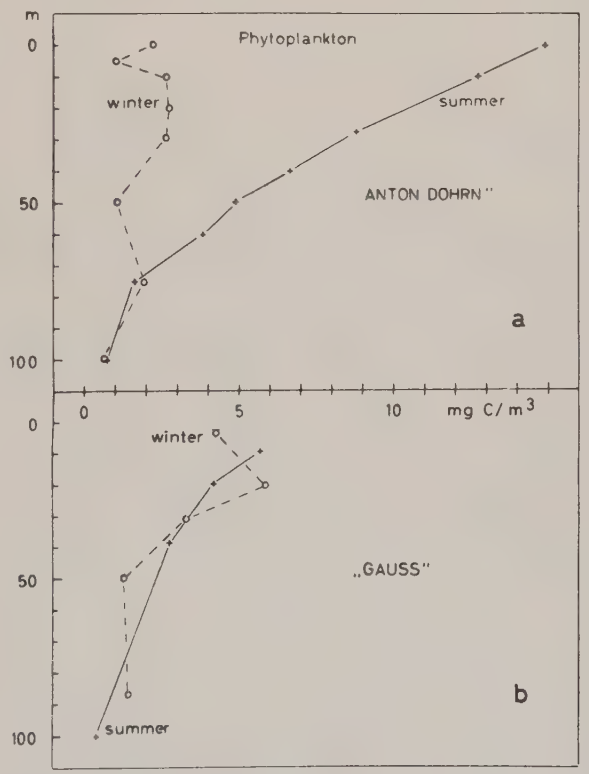

Figure 1. Mean values of the vertical distribution of the phytoplankton in the Irminger Sea (a) and in the Gulf Stream system (b) in winter (March/April) and summer (August/September) 1958 expressed as mg carbon/m³.

*) Dedicated to Professor Dr. A. Bückmann at the event of his sixtieth birthday.

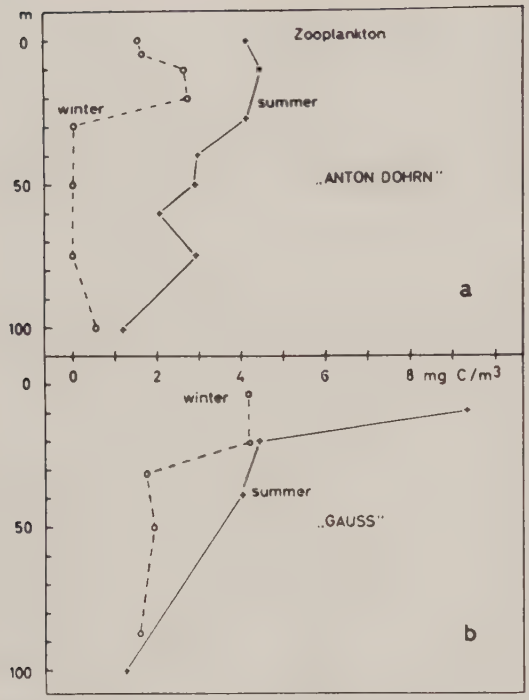

Figure 2. Mean values of the vertical distribution of the microzooplankton as in Figure 1.

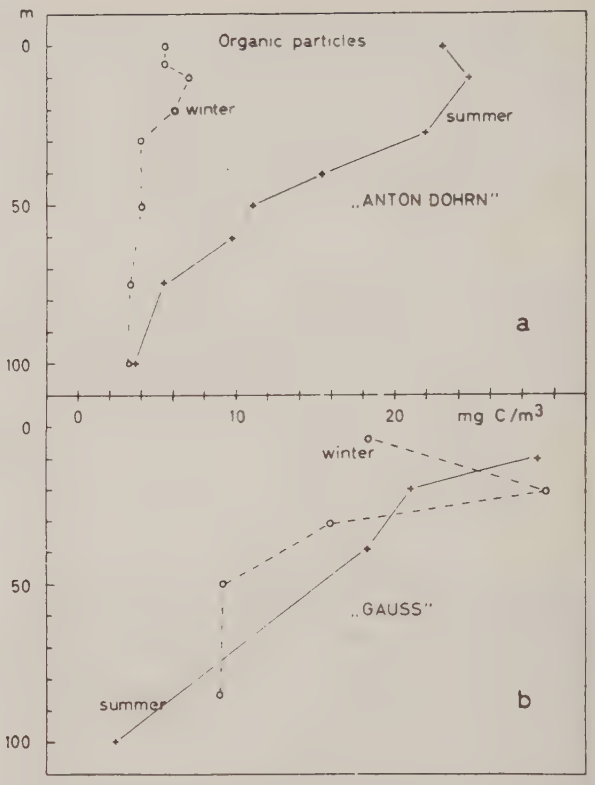

Figure 3. Mean values of the vertical distribution of the organic particles as in Figure 1.

carbohydrates. In this way a large number (1,800) of carbon determinations was carried out during the cruises.

Figure 1 gives the mean phytoplankton values expressed as mg C/m³. In the Irminger Sea (a) the great difference between winter and summer is seen, a fact which is known from higher latitudes. The Gulf Stream system (b) on the contrary gives a more tropical aspect, i. e., a constant population throughout the year if the region is taken as a whole. The microzooplankton distribution is much more complicated (Figure 2). It is supposed that the strong vertical gradients are not affected by discontinuity layers (in this case the phytoplankton would show a similar distribution) but by light intensity. In contrast to the phytoplankton the zooplankton seems to have a seasonal variation also in the southern region (2 b). There were great quantities of organic particles in the samples which could not be identified (Figure 3). There were certainly partly deformed phytoplankton and zooplankton cells, but the greater quantities were particles of destroyed plankton organisms. The value mg C/m³ is only a rough approximation, based merely on the numbers and diameter of the particles. Nearly the same vertical distribution is shown for the organic particles as for the phytoplankton. Compared with the northern region the southern one is richer in organic particles.

An illustration of these facts is shown in Figure 4. A section from Cape Farewell towards SSW (to the Newfoundland area) and from there towards SE (to the Azores) shows different plankton areas. All data given (also in the following figures) are average values from the surface to 10 m, and, horizontally, overlapping mean values from three stations. Figure 4 a gives the situation in summer. Only near Cape Farewell are great phytoplankton values encountered, as might be expected during this time of the year in or near the East Greenland Current. In other regions only more or less small quantities of phytoplankton are present. During winter (Figure 4 b) only near Newfoundland are found greater quantities of phytoplankton. We get the impression that also in lower latitudes we have to expect a great discontinuity in the distribution of phytoplankton and zooplankton. The organic particles contain no shells and no impermeable membranes and should therefore have approximately the specific weight of sea water and are able to remain for a long time in the upper layer without sinking. Under favourable conditions it is possible to find great quantities; sometimes, only small numbers of organic particles are present. If we compare the distribution of these particles with

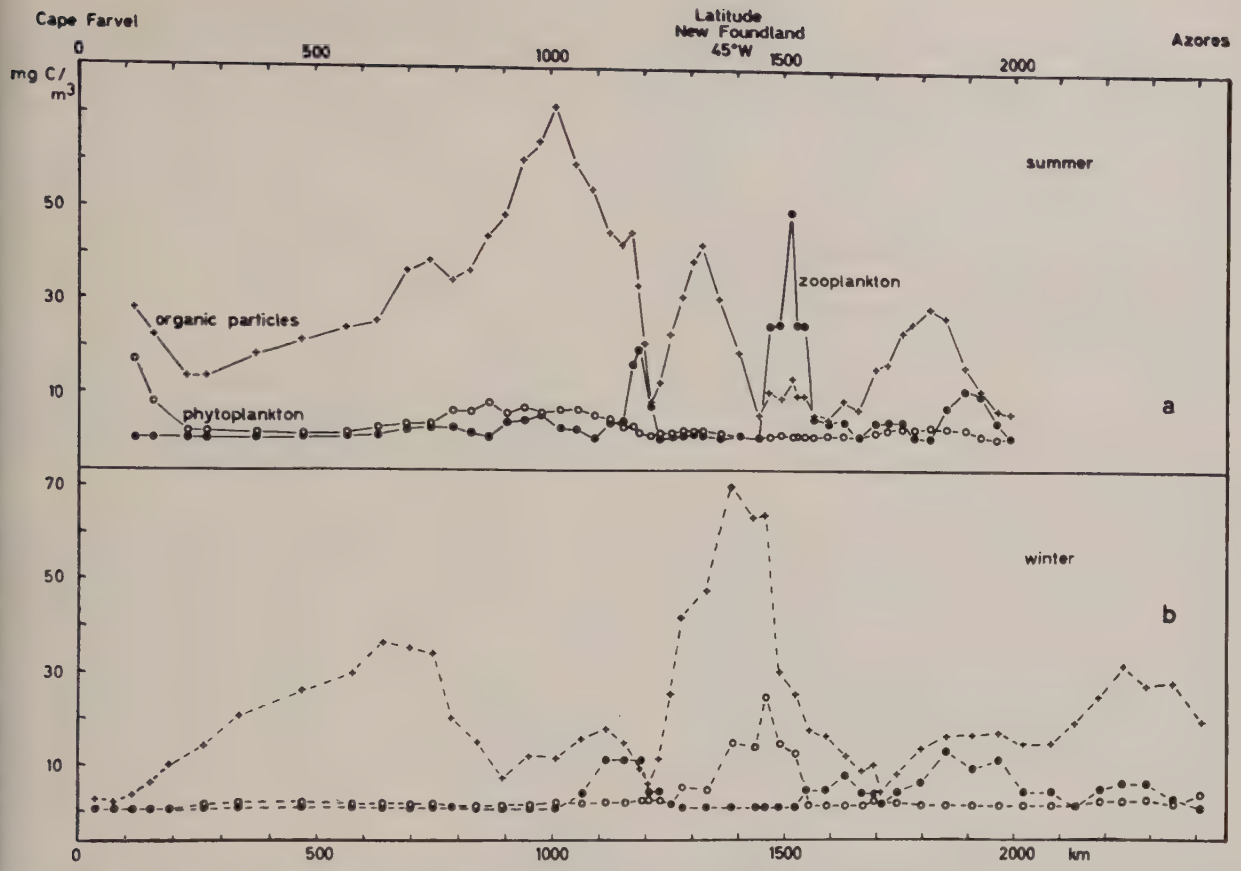

Figure 4. Surface values (0—10 m) from Cape Farewell to the Azores horizontally overlapping mean values from three stations (this is also the case in the following Figures) in summer (a) and winter (b) 1958.

that of the zooplankton, it is seen that in the neighbourhood of all zooplankton patches of considerable density only small quantities of particles are found. We may assume that the zooplankton is feeding on the organic substances and thus diminishing the number of particles. The zooplankton would starve if the small quantities of living phytoplankton were their only food. If this conception is correct we cannot expect to find constant zooplankton values also in lower latitudes. If there is food enough, the zooplankton will rapidly increase in numbers and in short time consume alle organic particles. The zooplankton patch must decrease by starvation if it is not transported to another region.

Figure 5 illustrates the relations between plankton data and total organic substances (permanganate oxidation) in a section from Cape Dan towards southeast. Figure 5 a shows the carbon values, 5 b the plankton data in summer, and 5 c in winter. In winter the quantity of plankton is very sparse, whilst in summer a reasonable value is observed. There is a negative correlation between the zooplankton and the organic particles. The phytoplankton values show a peak in the neighbourhood of the East Greenland Current and high values in the central parts of the Irminger Sea. The total organic matter does not change in quantity with the seasons in the Irminger Sea. It may, therefore, be assumed that there is always a certain stratification. Otherwise in winter time we should find the same carbon content as in the deep layers (0·22 mg C/litre) as in the upper layers. This is found only at one station near the East Greenland Current. In this region we may therefore expect a strong circulation from surface to bottom. Also during summer a minimum is seen here whilst nearer to the shore a strong phytoplankton population has produced great quantities of organic substances in the surface layers. So we may hope to find a certain correlation between phytoplankton and total carbon during summer (Fig. 6). This method shows two different types of water. The correlation coefficient between phytoplankton and total carbon

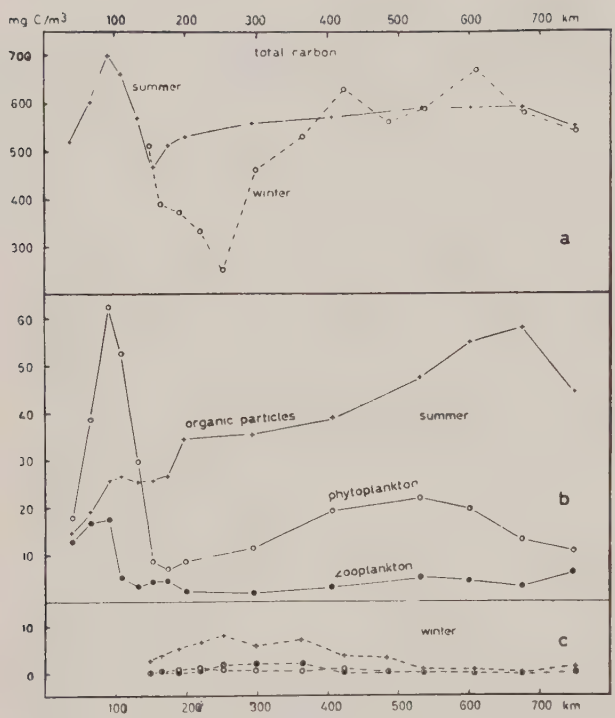

Figure 5. Surface values from Cape Dan towards SE in 1958.

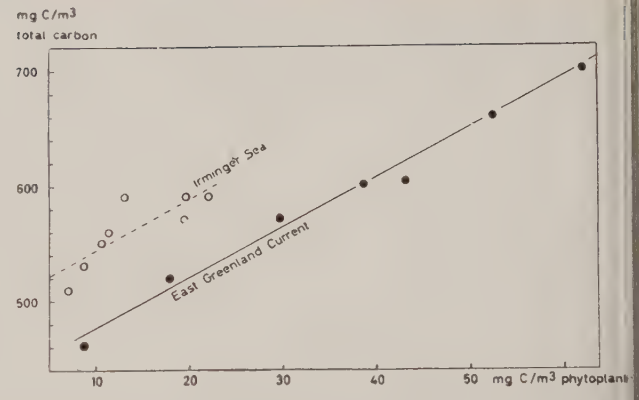

Figure 6. Correlation between phytoplankton and total carbon on a section from Cape Dan towards SE in summer 1958 (Figure 5).

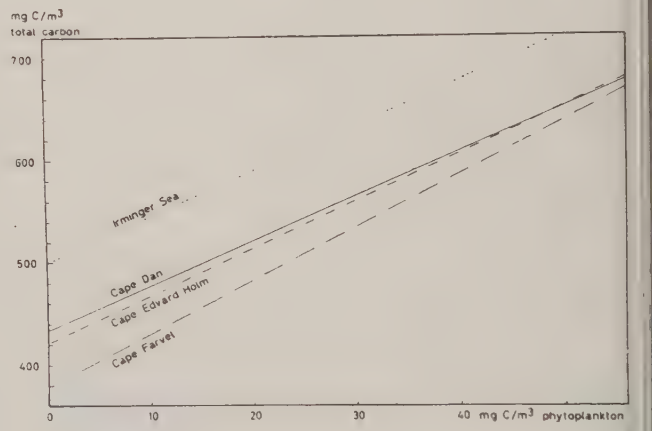

Figure 7. Correlation between phytoplankton and total carbon on different sections in summer 1958 (surface values).

is nearly the same in the two cases. An increase of 1 mg phytoplankton carbon corresponds to an increase of 4·3—4·4 mg total carbon. The initial values, however, are different. In the Irminger Sea we have high carbon values during winter and so we find great quantities of carbon in summer even in the absence of phytoplankton. In the region of the East Greenland Current lower values are found. Figure 7 gives the correlation between phytoplankton carbon and total carbon in the section near Cape Dan and in the Irminger Sea and near Cape Farewell and Cape Edvard Holm in the area of the East Greenland Current. The three values from the region near Greenland indicate that the quantity of total carbon which corresponds to 1 mg of phytoplankton is a function of the carbon content without any phytoplankton (i. e., the initial carbon content). This is even more apparent in Figure 8 which gives the correlation between the correlation factor (△ carbon: △ phytoplankton) and the carbon content at the beginning of the bloom. We find a linear function between the correlation factor and the carbon content at the beginning of the bloom in the East Greenland Current. How may this be explained? On one hand, the phytoplankton produces organic substances and on the other, all organic material is decomposed by bacteria. If we now suppose that the activity of the bacteria is directly proportional to the quantity of the total carbon, it would follow that high decomposition corresponds to high carbon values. Therefore in this case the effect of the phytoplankton can only be small, as shown in the diagram. This simple explanation is of course only correct as a first approximation. Actually from a theoretical point of view it is a very complicated system. At any rate this is a useful basic interpretation of the facts. This correlation will only appear in a series of determinations carried out in the same water mass under identical biological conditions. The value of the Irminger Sea for instance, does not correlate with the other data. It is supposed that in this area great quantities of *old* organic matter occur in the upper layer because high carbon values near the surface were also present during winter (Fig. 5), i. e., it must be expected that the bacteria have meanwhile decomposed that part of the old substances which was usable. The decomposition of the remaining organic matter will take a

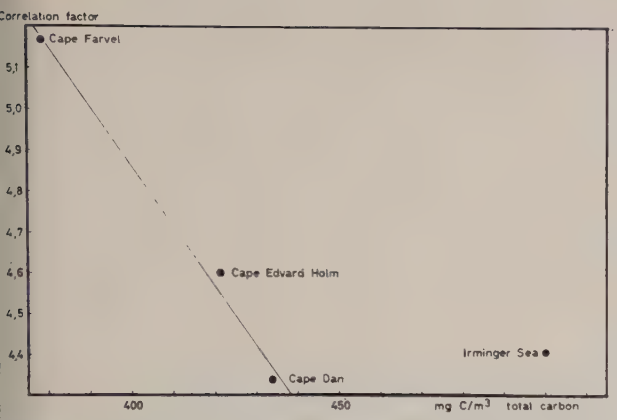

Figure 8. Correlation between △ carbon : △ phytoplankton and carbon content at the beginning of the bloom (explanation, see text).

long time. In this way the decomposition is slight compared with the other region. Other factors of course may contribute. At any rate the biological situation is different in this respect in the Irminger Sea from that of the East Greenland Current.

In two very small sections from the Gulf Stream system a negative correlation between △ total carbon and △ phytoplankton carbon was found. No explanation can be offered owing to the scantiness of the material. It might be that there had been a heavy phytoplankton bloom in the water in the western part of the Atlantic, which produced a great quantity of organic substance. Later on this water body was carried by the Gulf Stream into the area investigated. Owing to the higher water temperature a strong decomposition of the organic matter takes place. Under these conditions the bacteria might decompose the organic substances faster than the phytoplankton produces them. At any rate, a larger number of investigations in different parts of the oceans are urgently needed. A comparison of the conditions near the Polar Front with those of lower latitudes would prove extremely useful.

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10.

The Vertical Distribution of Seston in the Northern North Atlantic, as Observed during the Cruises of "Gauss" and "Anton Dohrn" in Late Winter and Late Summer of 1958

By

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Seston represents the particulate matter in the pelagic zone and is known to be in the order of magnitude of one μ to 10 mm. It consists of organic and inorganic substances, the organic being divided into a living part and the detritus. The biotic seston represents the main quantity of food for all filter-feeding animals and is therefore of greatest interest as regards the metabolism in the sea. Generally it represents the main part of the biomass in the pelagial.

We may expect that autochthonous seston will occur in larger quantities on the left side of the large oceanic currents in the northern hemisphere, because the deep water, which is rich in phosphorus etc. mixes here with the surface waters. The newly formed living material becomes partly mineralized in the upper layer, and is partly incorporated by larger animals, a process which cannot be analysed by the methods applied here. Part of the seston will sink to the bottom. This part is of greatest interest for the problems of the nutrition of the deep-sea plankton and the bottom-living animals. From Danish and Soviet investigators we know the order of magnitude of the population at great depth. Bogorov (1957) gives the following average figures for the NW Pacific of the living substances (= biomass):—

Depth, m	0–50	500–1,000	2,000–4,000	6,000–8,500
Biomass (mg/m³)	498	56	9	2

Spärck (1953) gives an average number of 10 individuals/m² and 1 g living substance in 5,000–8,000 m depth (bottom). We know nothing of the metabolism of these deep-sea animals.

In the course of the IGY investigations good facilities were available on board the R/V "Gauss" and "Anton Dohrn" for observations of the vertical distribution of seston on several sections in the northern North Atlantic. For different reasons 1,664 samples were taken from depths of only 0—1,500 m and a few (17) samples above the bottom between 2,500 and 4,800 m. The vertical distribution is in outline as follows (Krey, *et al.*, 1959).

In the northern part of the section from Cape Farewell to the Azores we observe in late winter as well as in late summer high values in the area south of the Cape. Probably this material includes a high percentage of inorganic matter originating from the melting ice of the East Greenland Current. In the southern part of this section average figures of up to 0·5 mg dry substance per litre are found in the surface layer. There are maximum quantities in nearly all places where we suppose that deep water mixes with that of the surface layer. During late winter the layer of higher values reaches deeper down than in late summer when a stronger stratification occurs at 40—60 metres.

As a further example, the section S of the Flemish Cap (Fig. 1) generally shows higher seston values in the southern part of the area where we may suppose that deep water rises to the surface. The same may be stated of the north/south section at 35°W (Fig. 2). From the section 28°W, 50°N to the coast of SW Greenland observations are available only in the surface layer down to 100 m depth. They show mainly the same pattern of distribution.

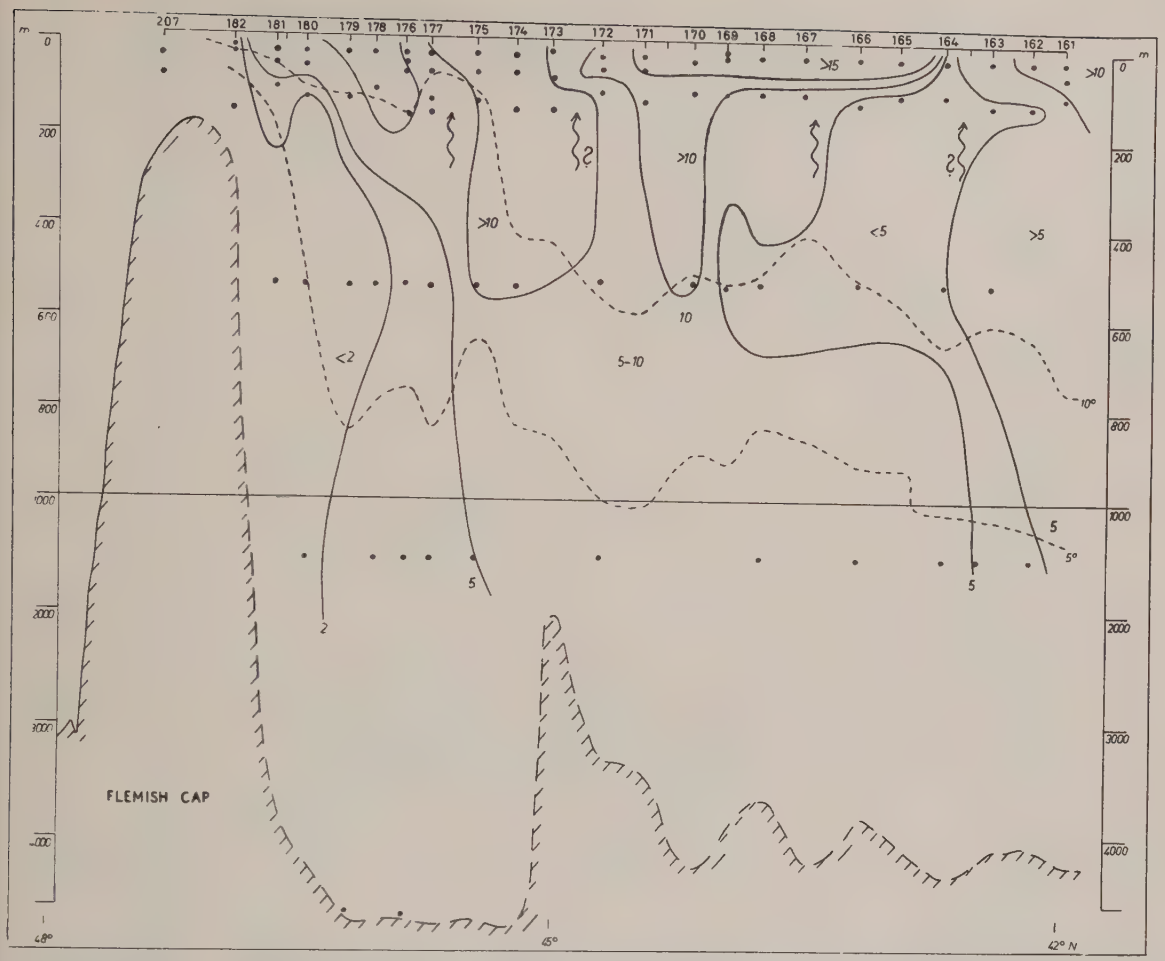

Figure 1. Isolines of seston (in mg/l) from a cruise of "Gauss" on a section south-east of the Flemish Cap (stations 207, 182—161) in late summer of 1958.

The autochthonous seston of the surface layer is reduced by grazing, which results in a destruction to smaller particles, e. g. detritus, and an accumulation of larger organisms and it is further reduced by mineralization and by sinking. In many places we can observe a certain enrichment with seston in deeper water layers (500—1,500 m), especially where the surface area is eutrophized. The concentration of particulate nutrients in waters > 1,000 m is under the same conditions measurably higher in eutrophic areas than in oligotrophic, so that we may expect to find a larger population in the former areas as well in the pelagic as in the benthic zone, at comparable depths. The mean vertical distribution of seston (Figs. 3 and 4) shows that an area with higher seston values at the surface also has higher values at depths of 500 m and 1,500 m. Figure 3 a represents the general vertical distribution over the whole area investigated by the "Gauss" in the late summer of 1958. In Figure 3 b it is demonstrated that in the central part of the Gulf Stream the surface values of seston are relatively low (0·13 mg/litre) and only amount to 0·06 mg/litre at a depth of 1,530 m. The corresponding figures for the middle section (35°W, Figure 3 c) are much higher at the surface (0·30 mg/litre) as well as at a depth of 1,530 m (0·08 mg/l). The mean surface values in the following E section shows a still higher concentration of seston (0·42 mg/l). Generally we suppose that the Gulf Stream is relatively oligotrophic in its centre. The farther this stream runs to the NE, the more it gets mixed with deep water rich in inorganic dissolved nutrients. At the same time the layer of surface water is reduced in its vertical extension and by this the light conditions for the development of the phytoplankton become better.

Figure 4 a gives the state of the mean distribution

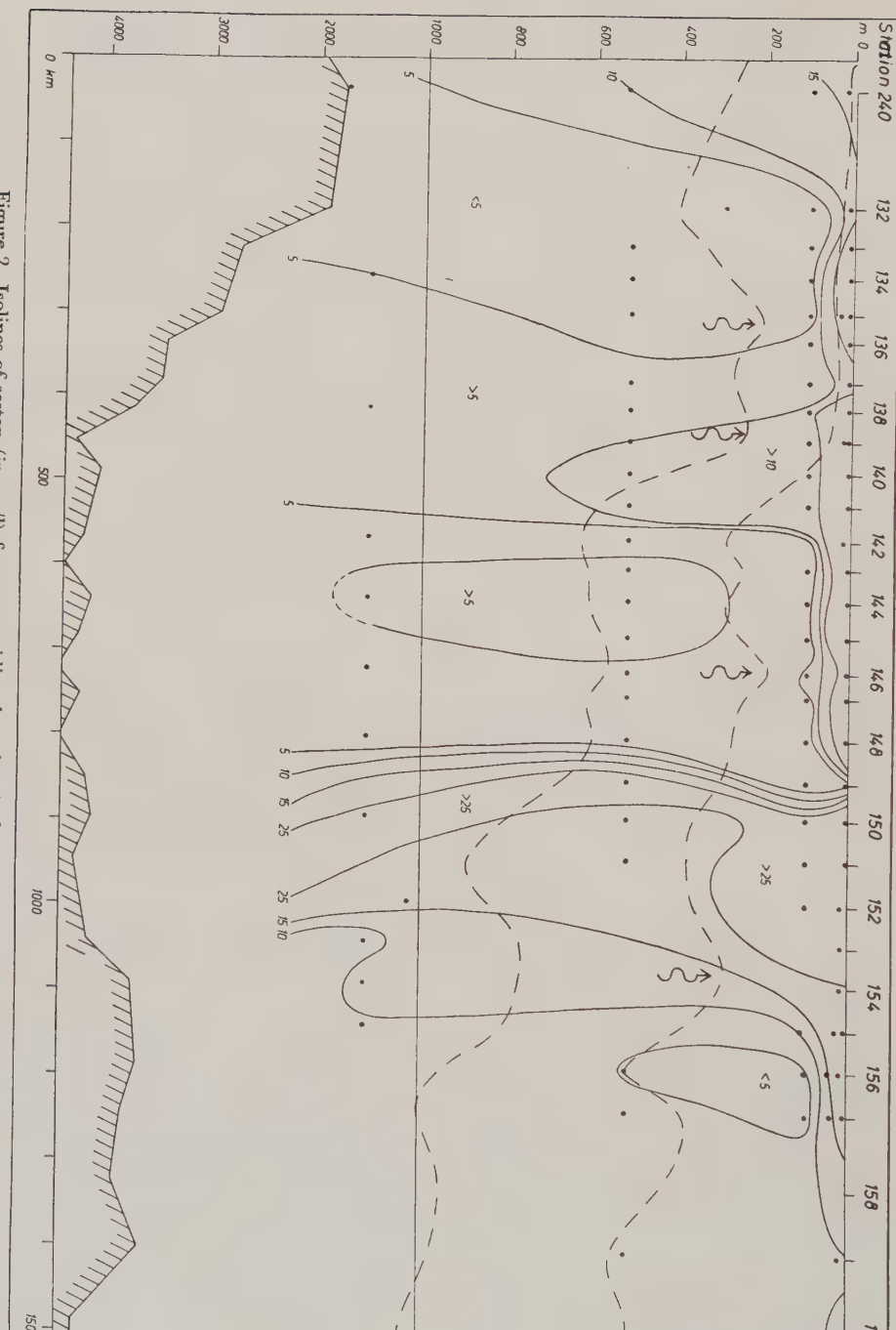

Figure 2. Isolines of seston (in mg/l) from a meridional section (35°W, stations 240, 132—161) in late summer of 1958.

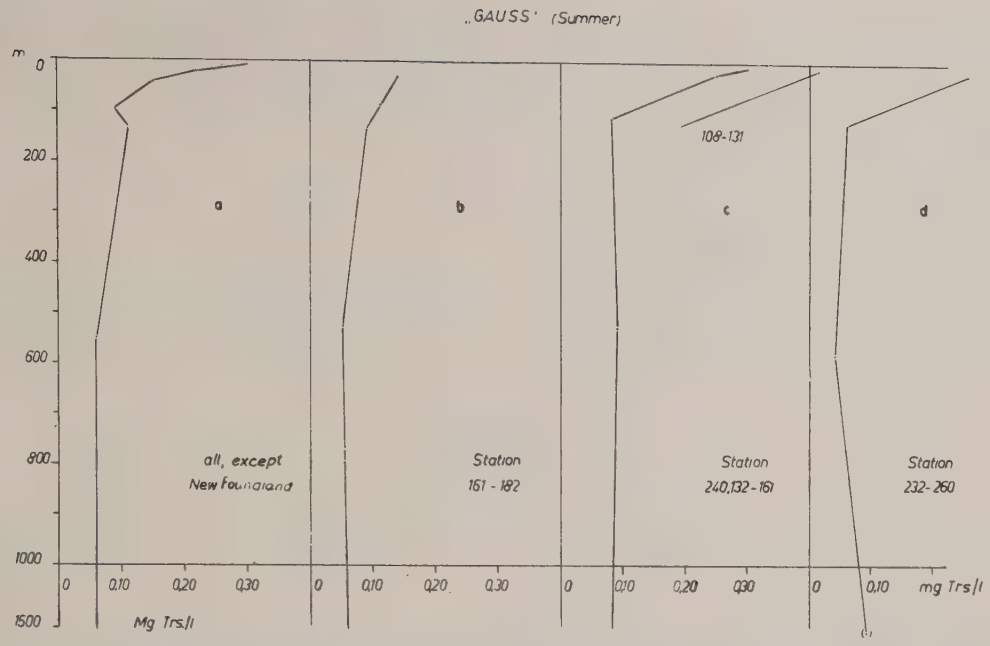

Figure 3. Mean vertical distribution of seston (in mg/l) during the cruise of "Gauss" in late summer of 1958.
Mean values from:
a. All stations except those around Newfoundland.
b. Mean values from the westernmost north-south section.
c. Mean values from the median north-south section (35°W).
d. Mean values from a west-east section at 55°N.

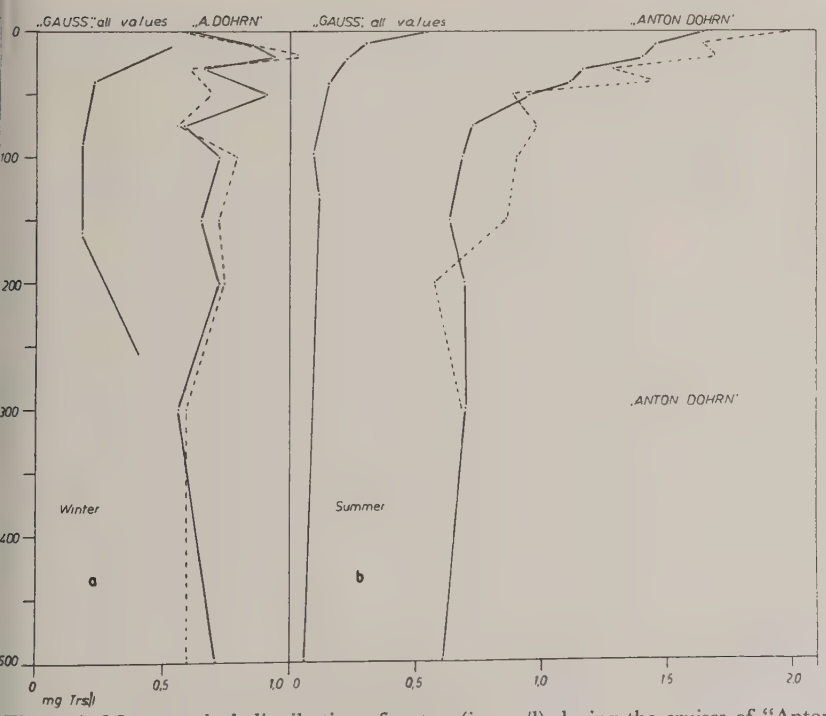

Figure 4. Mean vertical distribution of seston (in mg/l) during the cruises of "Anton Dohrn" and "Gauss" in 1958.

a. Late winter 1958:
right side = observations of "Gauss".
left side = observations of "Anton Dohrn".

b. Late summer 1958:
left side = observations of "Gauss".
right side = observations of "Anton Dohrn".

—— = all values.
– – – = values east of the border line.

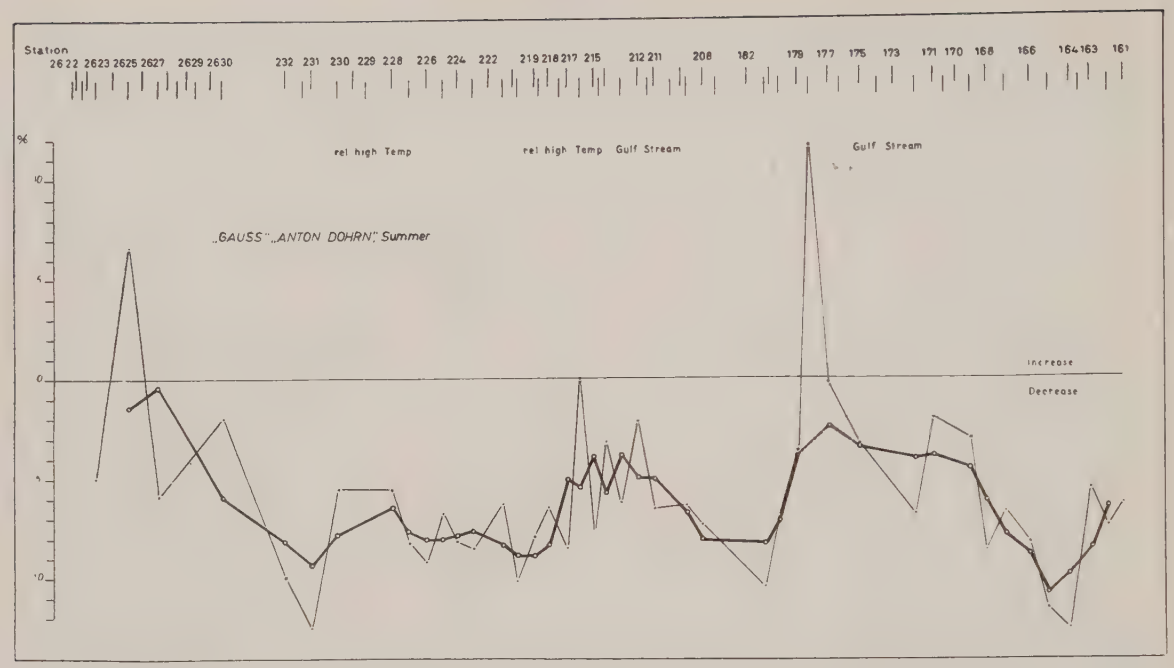

Figure 5. Reduction of the weight of seston from the surface down to 100 m in % of the initial weight along a section from Cape Farewell to the Azores. Solid line = overlapping mean values.

of seston during the late winter in the area covered by the research work of "Gauss" and "Anton Dohrn". The differences between the observations made by these two vessels are remarkable. The high figures observed by "Anton Dohrn" in the northern area may partly be caused by the inorganic particles, delivered from the melting ice. This may be supported by the fact that the values decrease with the depth only to a small degree. The distribution of oxygen shows no essential decrease in the depth. On the other hand, the mean values from the Eastern part of this area, where we cannot expect an influence of the melting ice, are not much lower than the other (broken line).

The mean state during the summer 1958 is given in Figure 4 b. Here it is evident that the southern area covered by the investigations of "Gauss" is less eutrophized than the northern, where "Anton Dohrn" took the samples. This is obvious in the surface layer as well as in 500 m depth. This statement has to be explained by the analysis of chlorophyll and protein, not yet worked up.

The reduction of the seston weights in correlation with the depth is an important problem for the nutrition of filter-feeding animals in the planktonic and the benthic zones. We may calculate this reduction by the following formula:—

$R = \frac{a_1 - a_2}{T_2 - T_1} \times 10$ and take this in % of a_1, wherein

a_1 = seston in mg/l in the depth of the upper level T_1 and

a_2 = seston in mg/l in the depth of the lower level T_2

As an example, Figure 5 can show the course of this factor along the main section from Cape Farewell to the Azores during late summer of 1958. Here, the figures for each station have been calculated for the uppermost 100 m. The single values show relatively high differences, in some cases even an increase of seston with the depth may be observed. But if we calculate the overlapping mean values, the trend becomes more visible, and we may distinguish 3—4 areas of relatively low reduction of the biomass with the depth. The hydrography of these areas shows that they are situated in the area of the branches of the Gulf Stream resp. Irminger Current. It is probable that here the turbulence causes a more thorough mixing of the seston, so that the differences between the upper and the lower levels become smaller. By further analysis of the protein values we can decide whether this reduction is caused by real mineralization or by accumulation.

We may expect great changes in the composition of the seston according to the depth. This has been shown by the recent investigations of Hagmeier (MS,

1960) in Icelandic waters. In many places in the surface layer he found 50—60 % of the seston consisting of living plankton. Already in a depth of 50 m he observed only 2 %. One typical station from the ice border may be given:—

Depth in m	0-10	20	120	220	320	420
Seston mg/l	2·4	0·7	0 7	0·9	0·6	1·3
% phytoplankton	59	11	0	1	1	0·1
% zooplankton..	0·3	0·4	0	0	0	0

Further analysis of the rich material gained during the cruises of the IGY will show the different composition of the seston of living and dead material.

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11.

Zooplankton Observations at Ocean Weather Stations I and J in 1957 and 1958

By

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Introduction and Methods

The four British Ocean Weather Ships take turns at manning stations I, J, K, and A, and while on station they take zooplankton samples weekly. During 1957 and 1958, most voyages were to station I (59°N, 19°W) and J (52°30′N, 20°W) and the frequency of sampling is shown in Table 1. Gaps in sampling are due to voyages to other stations, bad weather, or damage to nets. Most of the hauls are taken in late evening or night, between 2130 and 0230 GMT, but a few were taken in the middle of the day. The net used is made of No. 3 silk (60 meshes to the inch) and has a conical canvas top-piece with upper ring 40 cm in diameter and lower ring 50 cm in diameter. It is hauled vertically from 100 m to the surface, and theoretically filters 12·5 m^3 of water per haul.

In presenting this summary of results only a few species or groups of species are considered and they are mostly those reported on regularly in the *Annales Biologiques* by workers at Edinburgh and Aberdeen.

Copepoda

At station I in 1957 the numbers of copepods remained below 250 per sample until early March. At the end of April and in May they increased to about 10,000 per sample with *Calanus finmarchicus, Metridia lucens,* and *Oithona* as the dominant species. In July *Oithona* and *Acartia clausi* were most numerous but the total numbers were not above 5,000 per sample until the end of the month: they then began to increase towards a peak in mid-August when one sample contained 138,000 copepods of which almost 90 % were *Acartia.* The peak numbers of *Pseudocalanus* and *Paracalanus* also occurred at this time. Numbers declined during September to about 5,000 in November, mostly *Acartia.* In 1958, numbers were again low until mid-March. Between then and July only two samples were taken. In July, numbers were higher than in 1957, reaching 25,000 and this was mainly due to an earlier peak of *Pseudocalanus* and *Paracalanus* and a later increase in *Calanus finmarchicus. Acartia clausi* was again dominant in August but the largest sample contained only a quarter of the peak numbers in 1957. From mid-September to November there were between 4,000 and 1,500 copepods per sample, again mainly *Acartia.*

At station J sampling was poor in 1957. By the end of March there were about 7,000 copepods per sample, with *Metridia* dominant and *Paracalanus* and *Oithona* also important. The samples contained very few *Calanus finmarchicus.* In July *Acartia, Paracalanus,* and *Pseudocalanus* were dominant in total counts of about 10,000. In 1958, the seasonal pattern of copepod numbers was similar to that at I with about 10,000 per sample in April, 30,000 at the end of July, 5,000 in September, 10,000 in October, and 2,000 in November. *Paracalanus* was generally dominant throughout the year with *Acartia* less important. Other species which assumed importance at times were *Centropages typicus* in late July and *Pleuromamma* spp. in September.

Thaliacea

Salpa fusiformis and *Dolioletta gegenbauri* were the common species and did not usually occur together. *Thalia democratica* occurred only in 3 hauls at J in October 1958.

Salpa fusiformis showed different distributions in the two years. In 1957 at I, a few specimens were caught in late May; in July and early August it was abundant and by September there were none. At J only one specimen was caught and that on 10. July. By contrast in 1958 only one specimen was caught at I (4. July) while it was common in samples at J

Table 1. Numbers of hauls per month

		Month											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Station I	1957.....	3	4	1	1	5	1	6	3	3	–	2	2	31
	1958.....	2	2	3	–	2	–	4	4	5	3	2	2	29
Station J	1957.....	2	–	4	3	–	–	4	–	1	1	–	2	17
	1958.....	4	–	1	4	–	1	3	6	2	5	3	–	29

n late March and April and abundant in a sample n late June; none were caught after 9. July.

Dolioletta gegenbauri was more abundant at both tations in 1957 than in 1958. At I in 1957, none vere seen before mid-May, but large numbers were aught between then and mid-July. At J a few speci- nens occurred in March and April and large numbers n July (no samples in May and June). In 1958, the nly specimens at I were in late May, while at J a ew were caught from late March right through to ate November, with large numbers in mid-August.

Pteropoda

In contrast to *Dolioletta* both *Limacina retroversa* nd *Clione limacina* were more abundant in 1958 han in 1957.

In 1957, *Limacina* was recorded at I only in August nd early September, and single specimens of *Clione* vere taken in late May and twice in November. At neither species was recorded.

In 1958, *Limacina* occurred at I from May through o December with large numbers (over 1,000 per ample) from mid-July to early September. *Clione* vas taken in small numbers from February to October vith over 50 specimens in samples on 29. August and . September. At J *Limacina* had two periods of bundance in April and late August to late October. There were no samples in May and no specimens in amples in July and early August. *Clione* occurred n small numbers in March, April, August, and Oc- ober.

Medusae

At both stations *Aglantha digitale* was present in he first half of the year only, being absent from August onwards. At I in 1957, between 100 and 600 per sample were present from April to early June but the largest number at J was 35 on 5. March. In 1958, the peak numbers were later at both stations, 280 on 9. July at I and 280 on 30. April at J.

Cladocera

Attention has previously been drawn to the so-called "neritic" species *Evadne nordmanni* which is often found in large numbers at these oceanic stations. In 1957, very large numbers (up to 25,000) were caught between mid-May and mid-July at I and in mid-July at J (1,500). In 1958 it was less common and was recorded only on 22. May at I and on 30. June, 20. July, and 12. August at J.

Summary

The zooplankton fauna at stations I and J, about 400 miles apart, is generally similar, with the southern station J showing more variety of species. The seasonal increase in numbers of the more abundant species usually takes place about a month earlier at J than at I, as also does the phytoplankton increase.

Several differences between the years 1957 and 1958 have been noted, particularly:—

(i) The larger number of copepods in July 1958 than in July 1957.

(ii) In 1957, *Salpa fusiformis* was common at I and almost absent at J while the opposite occurred in 1958.

(iii) *Dolioletta gegenbauri* was more abundant in 1957 than in 1958.

(iv) *Limacina retroversa* and *Clione limacina* were more abundant in 1958 than in 1957.

12.

A Further Contribution to the Oceanic Mycology*)

By

W. Höhnk**)

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Since 1952 we have carried out the study of fungal life from fresh water to sea water and now to the depth of the ocean.

The initial results in the field of marine mycology are remarkable and encouraging. It was the search for saprophytic fungi which led to a better understanding of the distribution of fungi and their reactions to saline water.

In the course of our collections we learned that not only the lower fungi (previously known as "water fungi") can be found in water but also the "higher fungi"; *Fungi imp.* and *Ascomycetes* frequently appear in brackish water as well as in sea water. On the whole they represent a distinct part of the community in the sea and their volume increases with increasing salinity.

We have further learnt by cultural work that the optima of the three life phases of the filamentous *Phycomycetes* corresponded to a certain range of salinity. If the degree of salinity values is markedly changed, the life cycle becomes gradually shortened. At first the sexual phase is dropped, then the sporulation and thereafter the growth becomes atypical, and finally the individual dies and the species is eliminated. In addition, certain relations have been described for a series of higher fungi which exist between the salinity on the one hand, and growth and reproduction on the other. Thus it is possible to describe a certain mycelium in a given level of salinity as endemic, inhabitant, or migrant, and it is clear that fresh water, certain zones of brackish water, and the open sea all have their own characteristic flora.

The composition of the fungal community as a function of increasing salinity is depicted in Figure 1. We grouped the collected fungi from 510 samples according to their indigenous habitat and drew spectra for four different ranges of salinity values, which are to be found from the oligohaline zone to the open sea.

The characteristic feature of Figure 1 is the gliding line in the change of the constituents: at first the sexual forms of the Saprolegniaceae disappear and then the asexual species. The same holds good for the Pythiaceae, but for higher values of salinity. The saprophytic species of both groups fade away in low and medium salinity. Only the parasites, which complete their life cycles within their hosts, are still to be found in sea water. For example, *Leptolegnia baltica* causes an epidemic among *Eurytemora hirundioides*. *L. marina* and *Plectospira dubia* are found within the eggs, the embryos and the individuals of *Pinnotheres* and shells and *Pythium* species are to be found within several plankton forms. To compensate for the disappearance of the two groups of fungi the portions of the remaining groups, especially that of the higher fungi (*Ascomycetes* and *Fungi imp.*) increase in sea water.

Of the 510 samples mentioned, 344 were taken from the soil. The spectra for the yields from them showed the same feature. This experience became valuable in view of our method of collecting material.

A lethal limit for the fungus flora as a whole was not found. The presence of the fungi in sea water is

*) Dedicated to Professor A. Buchmann's 60th birthday.

**) The support of the Deutsche Forschungsgemeinschaft and the Deutsche Wissenschaftliche Kommission für Meeresforschung is gratefully acknowledged.

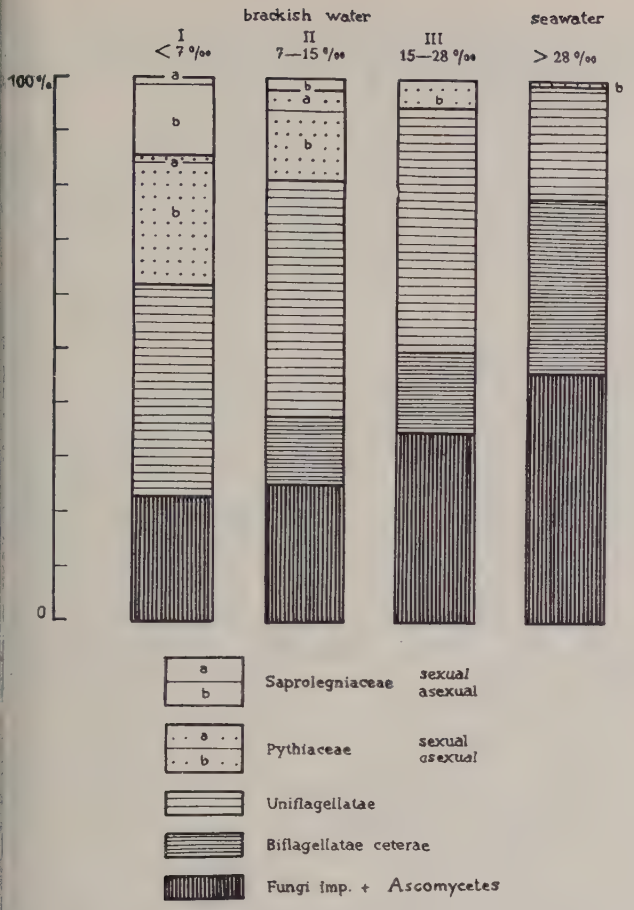

Figure 1. Fungus spectra for four steps of salinity.

a fact which is proved both by the results of our collections and by cultural work, but it remained to be seen whether in the open ocean, with its depth and other factors the fungi are allowed to play a role of ecological importance, as they do elsewhere.

The voyages of "Anton Dohrn" during the IGY in 1958 offered the opportunity for such an inquiry. As mentioned above the saprophytes were the main object of our investigations. Do they have the importance as suggested; if so, then they should be found regularly. In comparison, the parasites are only those organisms which are able to carry out effective attacks upon life. Their capture depends much more upon chance than the finding of saprophytes. For the capture of saprophytes, water and soil samples and also shifting matter were used. We took all of them, but much preferred soil samples from the bed of the ocean and the shelf. They were taken from 94 stations of depths down to 3,425 metres. Generally, samples down to about 500 m were taken by means of the

Figure 2. The Pratje corer on the way up.

van Veen grab and from greater depths at 41 stations by the Pratje corer (see Fig. 2).

The corer has a metallic tube measuring 2 m in length and 45 mm in width. The upper end carries a head-piece 40 cm long in which a beaker-like plug slides up and down. In the mouth-piece at the lower end is a flap. On the way downwards the lower flap and the upper plug are opened, and on the way up they close the openings and so prevent the loss of the soil. In the laboratory, the soil content of the corer is pressed by a stamper into plastic tubes or sample beakers.

For the preparation of the raw cultures 100 cm^3 Erlenmeyer flasks were preferred to Petri dishes (Fig. 3). We took 5—20 cm^3 of a soil sample from each raw culture and put it into the Erlenmeyer flasks. For watering the samples taken on the shelf we used sea water taken from the surface near Iceland and Rockall, and for the samples from the bed of the ocean deep-sea water was used. All the water was filtered through membranes, rough, fine, and finest. About one day later we added the sterilized "baits", consisting of the pollen of several *Pinus* species, straw, the seeds of several plants, and "cellophane". According to our experience it is not necessary to make the first microscopical inspection before the 12th day and even a longer waiting period is to be recommended.

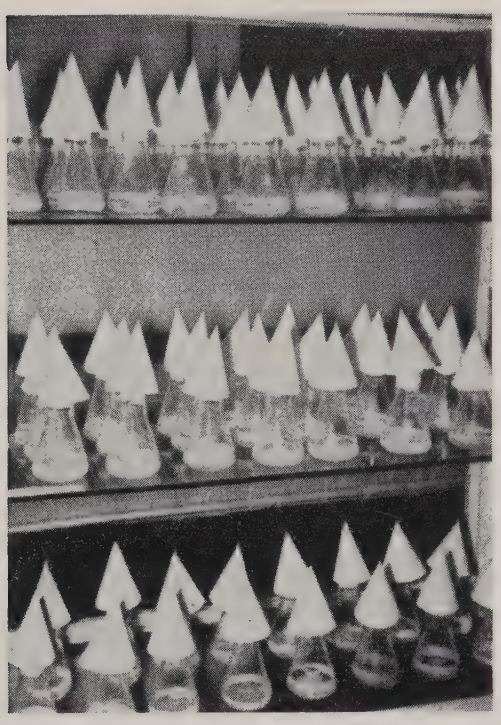

Figure 3. Erlenmeyer flasks containing raw cultures.

The preparation of the isolates should start as early as possible, for in competition with lower fungi, *Fungi imp.* will dominate. For the isolation of the lower fungi we used the van Thiegem chamber, and of the higher fungi we mostly employed Würze or Czapek-Dox agar plates.

Later on the daughter cultures were simultaneously subjected to a set of different temperature conditions. They were grown at 3°C; 7·5°C; 16°C and at room temperature. In this way we tried to learn about the optimal conditions and about the optimal reactions of the fungus in question. The optimum is the temperature at which the fungus shows its life cycle regularly and in the shortest time and at which the fungus can be kept alive by feeding.

One is inclined to acknowledge as oceanic fungi only those mycelia which (a) grow and reproduce under submerged conditions, (b) thrive in sea water, (c) live at the temperature at which they were found, and (d) develop the specific life cycle of their fungus group.

The yields from the samples of soil are dealt with first and then the results of the water samples and shifting matter. Soil samples were grouped according to their depth, as deep-sea or those from the Ireland, Iceland, and Greenland shelves.

So far only 13 samples from stations near Iceland and Ireland have been treated; 12 gave a good to luxuriant fungal yield, and one gave none. The lower fungi dominated.

From the Greenland shelf samples from 25 stations located between 67°17′ and 59°2′N Lat. were investigated. Their depth varied from 128 m to 470 m. Of these samples 46 raw cultures were treated. Forty-two of these showed distinct to luxuriant yields, the remainder (4), none. Thirteen of the 42 raw cultures contained only *Phycomycetes,* 7 only *Fungi imp.,* and the rest, members of both groups. The character of the soils varied considerably. It was clayey, slimy, sandy, or stony and, in some cases, the grab contained only pieces of coral, sertularias, or sponges. It seems to be of importance to observe that the soil samples contained a fungal community in spite of the very low temperature of their surroundings. If fungi can be encountered at such places then the low temperature is not a lethal factor, even in deep-sea waters.

Of the 41 deep-sea stations Table 1 includes only those 12 which have been investigated so far. Of the 22 raw cultures that were treated, 20 produced fungi. Figure 4 gives a few illustrations of the fungi found, three of lower and three of higher fungi.

Besides the samples of soil we also treated some from turbid water collected by the hydrographers with their Nansen apparatus. At the first station from a depth of 4,610 m, a portion of the water was put into Erlenmeyer flasks and pollen of *Pinus montana* was added. To our surprise, after 12 days, a rich yield of *Phycomycetes* and of *Fungi imp.* had appeared. This event led to treatment of the water samples from 7 other stations too. The results are given in Table 2. It may be seen that the yield relation here is not so favourable as that of the soil samples (Table 1), for almost half of the stations gave no yield; but when we consider that in reality every fungus found in water from such great depths is a surprise, then the proportion of samples with yields is remarkably high.

Fischer (1894) has shown the presence of yeasts in sea water, and several other authors have since verified his statements; recently Kriss (1959) has studied the yeasts from the Arctic and Pacific Oceans. His methods of capture we, also, have applied with success.

Since our water samples were taken with the Nansen apparatus, which is open when lowered to the depths, it might be possible that the fungi were caught on the way down and did not, in fact, come from the greatest depth. This uncertainty led us to try to obtain fungi from the liquid within the bodies of sponges and holothurians. So far as yeasts were concerned the results were positive. More isolates of yeasts were made from drifting algae and from fish.

Table 1. Yields of the soil samples from the bed of the ocean
(For the geographical position of the stations, see Fig. 5)

No. of stations	Depth in m	Character of the soils	Yields of *Phycomycetes*	Yields of *Fungi imp.*
2562	1100	firm ground		+
2562	1100	firm ground		+
2646	1180	fine sand	+	+
2565	1570	granular/sandy	+	+
2491	15—1600	granular		+
2491	15—1600	granular	+	+
2491	15—1600	granular	+	+
2491	15—1600	granular	+	+
2491	15—1600	granular	+	+
2252	2180	clayey	+	+
2252	2180	clayey	+	+
2349	2340	loamy	+	+
2349	2340	loamy	+	+
2239	2612	Globigerinic slime	+	+
2586	2930	slimy	—	—
2247	2980	Globigerinic slime		+
2247	2980	Globigerinic slime	+	+
2486	2990	clay and sand	—	—
2246	3080	clay and slime Globigerinic slime	+	+
2246	3080	clay and slime Globigerinic slime	+	+
2343	3425	clayey	+	+
2343	3425	clayey		+

Table 2. Fungal yields from water samples in the deep sea

No. of stations	Depth in m	Character of the water samples	Yields of *Phycomycetes*	Yields of *Fungi imp.*
2483	1400	turbid	+	
2483	1400	turbid	+	
2483	1400	turbid	+	
2502	2100	turbid	—	—
2311	2200	clear	+	+
2509	2300	turbid	—	—
2495	2960	turbid		+
2494	3150	turbid	—	—
2237	3730	almost clear	+	+
2236	4610	almost clear	+	
2236	4610	almost clear	+	+
2236	4610	almost clear		+

On both the voyages with "Anton Dohrn" we "baited" also several unwashed captures of net-plankton. It was found that the water must be strongly diluted as soon as the slightest smell of putre-faction appears. At first we lost several samples, but from the others we produced mycelia as well as pollen fungi.

To these field data several experiences of work in the laboratory must be added.

1. When a couple of years ago, the author prepared a culture from a soil sample taken at almost 400 m depth in the vicinity of Copenhagen, on the seeds only two single stunted hyphae were seen. This situation did not change for two weeks, but when the sample was brought into a constant temperature of 4°C a luxuriant growth of *Fungus imp.* quickly developed. The same dependency between growth and low temperature does not hold for all fungi of the Atlantic. Several from the bottom flora grew at 3°C, and also equally well at 7° and 14°C. From the point of view of temperature, therefore, the sensitivity of the fungi treated is obviously different.

2. Several fungi from the ocean bed showed that the application of deep-sea water is advantageous to

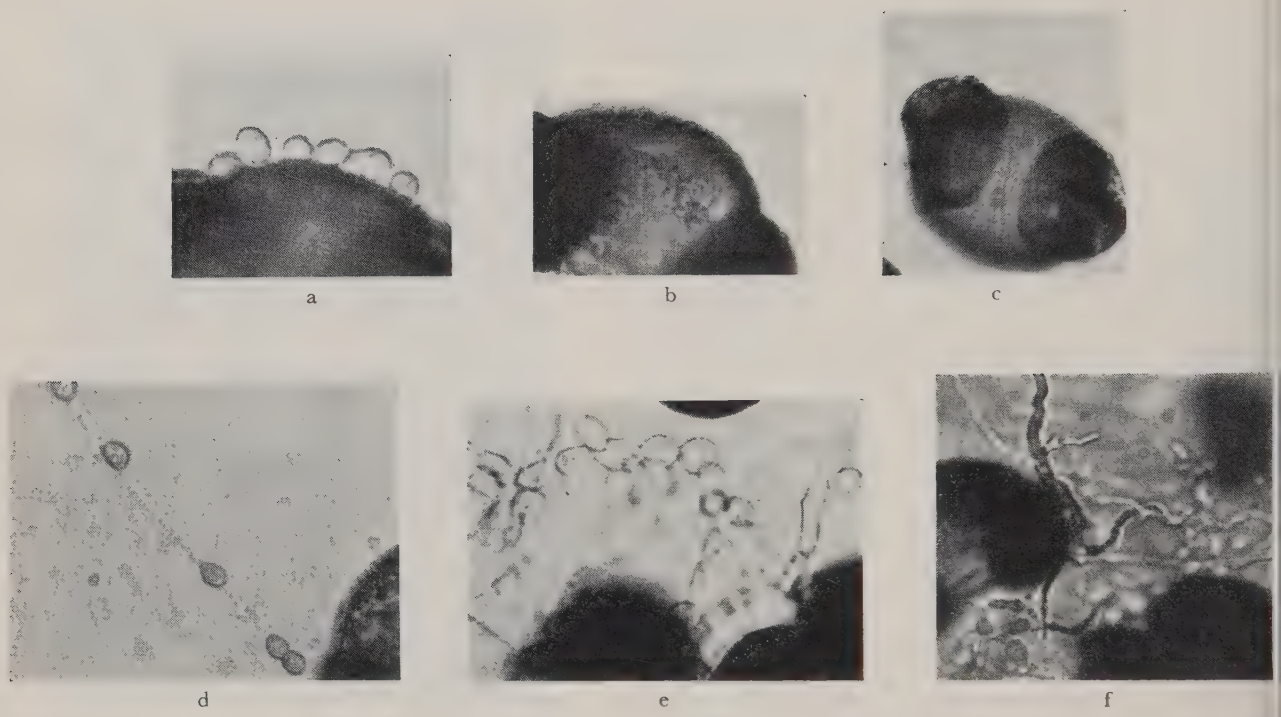

Figure 4. Deep-sea fungi at or within *Pinus* pollen.
Phycomycetes from (a) 380 m, (b) 2,850 m, (c) 3,425 m.
Fungi imp. from (d) 210 m, (e) 2,830 m, (f) 4,610 m.

Table 3. Chemical analysis of soil samples from the Greenland shelf and the bed of the ocean
(Dr. Dietrich, Bremerhaven)

	No. of sample	Depth in m	Permanganate $\frac{\text{o.s.}}{1,724}$ = C % dw.	N % dw.	C/N	P % dw. in extract
Greenland shelf	1	270	0·97	0·29	4·0	0·0037
	4	300	0·51	0·089	6·2	—
	82	165	0·25	0·09	3·2	—
	538	470	0·38	0·135	3·3	0·01546
	560	380	1·32	0·33	9·8	—
	518	128	0·13	0·025	8·8	0·01516
	555	211	0·35	0·075	8·4	0·04041
	19	320	0·52	0·095	7·1	0·0185
	525	330	0·31	0·105	5·4	—
	320	309	0·50	0·155	4·3	—
	299	425	0·30	0·095	5·5	0·01702
	599	165	0·7	0·07	4·9	—
	622	147	unseizable	0·03	5·7	—
	581	195	unseizable	0·045	2·9	—
	734	230	0·46	0·085	6·1	—
Deep sea	327	330	—	—	—	0·01182
	417	1100	—	—	—	0·01023
	442	3100	—	—	—	0·00969

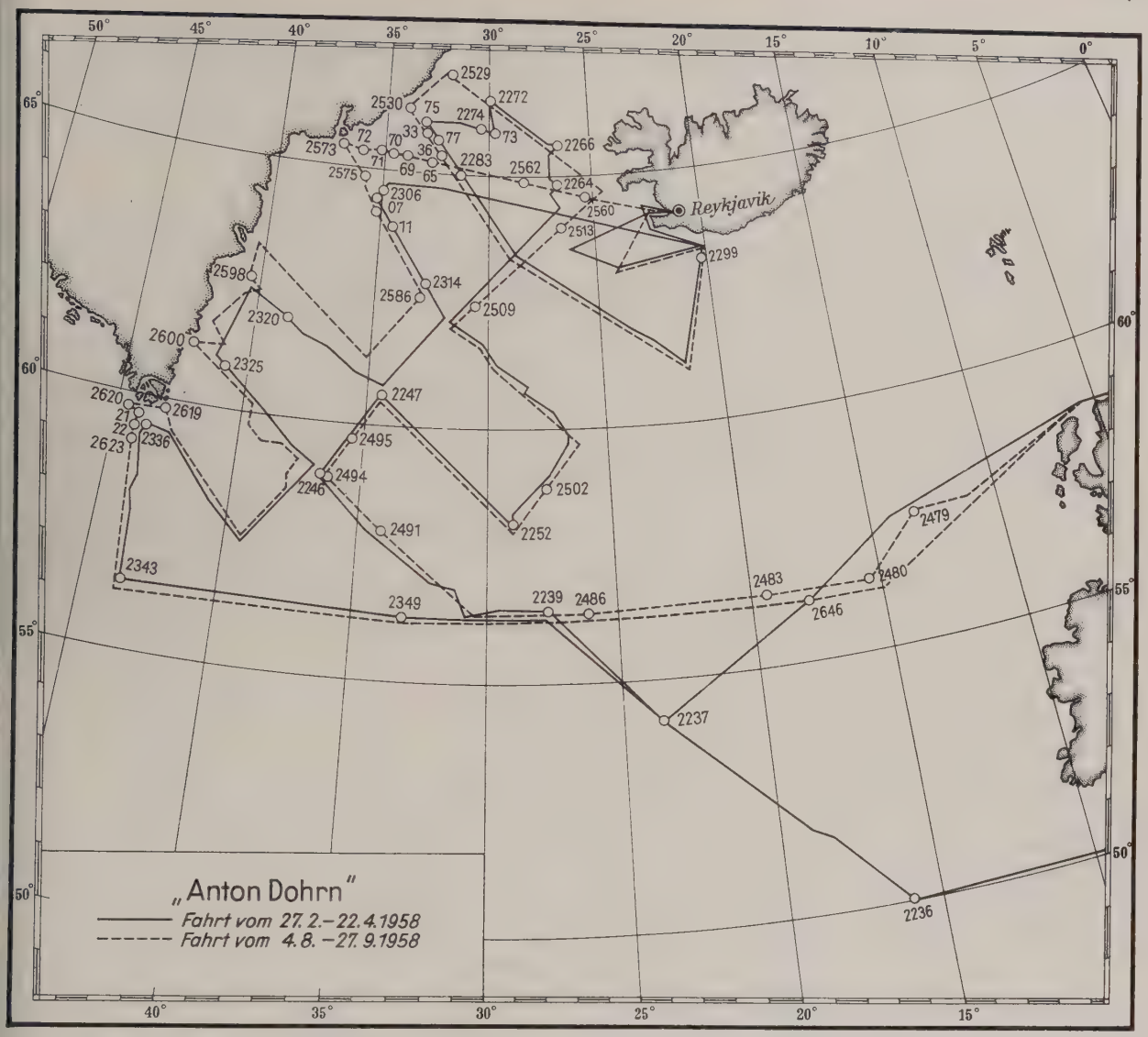

Figure 5. Geographical positions of the stations mentioned in the present paper.

he quantity and quality of the yield. The cause is not known, perhaps certain trace substances may play a ole.

3. Some deep-sea *Fungi imp.* produce much oil. It night be that it is a matter of degeneration. However, t is by no means certain, for the process happens in elatively young mycelia as well as at two different evels of temperature, one of which is the temperature f the station in the Atlantic.

Personally I remember a similar situation which ccurred a couple of years ago when I isolated a pecies of *Ceratostomella* from submerged wood from rackish water. We extracted from it an oil of good quality containing vitamins E and D and also traces of carotin. Becker, Kampf, and Kohlmeyer (1957) have shown that a species of *Limnoria* uses food prepared by fungi, and even fungal mycelium as food. It may be possible that such animals take their supply of vitamins from fungi too. Kriss fed a *Nereis* species exclusively on dried yeasts; after a fortnight the *Nereis* individuals increased their weight two- or fourfold. The possibility of an existence of a food relationship between fungus and animal on the ocean bed is suggested. Their oil will probably be investigated at a later date.

4. The length of the soil cores brought up by the

corer makes the mycological investigation of layers beneath the sea bed possible. To date we have had positive results from places 20—24 cm below it.

5. Repeatedly the question is discussed as to whether the ocean bed offers enough food for fungal life. Oxygen is present and Table 3 gives information about the C, N, and P relationship. Our chemist, Dr. Dietrich, has analysed a series of the soil samples from the shelf and from the deep sea. According to the results, I must accept the words of Prof. Kalle, Hamburg, that so far as food is concerned the possibility for fungal life exists. The results of Schreiber (1930/35) may be recalled, he showed what exceedingly small traces of P were needed in order to revive the vitality of the algae he worked with.

The results obtained so far lead to the statement that the ocean has its fungus flora and the selective power of salinity, depth, and food relationship has been much overestimated in the past. This fact must also be considered in general biology as well as in ecology, physiology, and other studies. Its importance is not demonstrable today but must be worked on in the future.

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13.

Investigations on the Bottom Fauna in the Shelf Region off SW Iceland and SE Greenland during the Research Cruises with "Anton Dohrn" in the IGY

By

E. Ziegelmeier

Summary

By reason of the hitherto existing utilization of the extensive material of qualitative and quantitative bottom samples the following results could be established for the area of investigation.

According to the bottom samples the most important groups of macrobenthos in the whole area are the following:—

1. Polychaeta (43 %)
2. Crustacea (30 %)
3. Echinodermata (9 %)
4. Bivalvia (8 %)

In the Polychaeta the sedentary forms are in majority, the ratio of sedentary to errant polychaetes being about 10:1. The most abundant Crustacea belong to the suborder of the Amphipoda, their ratio to the remaining Crustacea found in the samples (Cumacea, Isopoda) being 9:1.

With respect to the composition of the bottom animals at the different stations, according to abundance and frequency of the macrobenthos, three areas can be distinguished unequivocally:—

I = The shelf area off SW Iceland.
II = The south-eastern Greenlandic shelf sea off the coast, NE Angmagssalik up to the Iceland-Greenland Ridge.
III = The South Greenland shelf area near Cape Farewell.

Area I (depth of the bottom samples from 123 m down to 468 m; quality of the bottom: mainly pure clay, sometimes clayey sand). Characteristic features of this shelf area are (a) the dense stocks of Polychaeta, (b) the frequent occurrence of Bivalvia, and (c) the nearly total absence of Crustacea. Of the average biomass (cm^3 per 1/10 m^2) in this area about 1/3 are polychaetes and about one-half are bivalves.

Area II (depth of the grab samples from 195 m down to 470 m; mainly gravelly to coarse sandy; clay, sometimes with stones). With respect to its biomass and the abundance this area belongs to the least settled in the area investigated. More frequently Brachiopoda, Amphipoda, Isopoda, and Echinodermata occur here.

Area III (depth of grab samples from 128 down to 210 m; coarse to gravelly clayey sand, with mainly small stones). In the shelf sea off Cape Farewell all benthos animals except polychaetes are less abundant than echinoderms and crustaceans (especially Amphipoda, see Ziegelmeier, 1959). In the average biomass the proportion of both these bottom animal groups is each 1/3. For polychaetes, the corresponding value is 1/8.

A detailed paper, especially the utilization according to ecological points of view will be published after all the observational material has been worked up in the series "Helgoländer Wissenschaftliche Meeresuntersuchungen".

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14.

The Distribution of Cod-Haddock in the Central and South-Eastern Barents Sea, September/October 1958

By

Lars Midttun

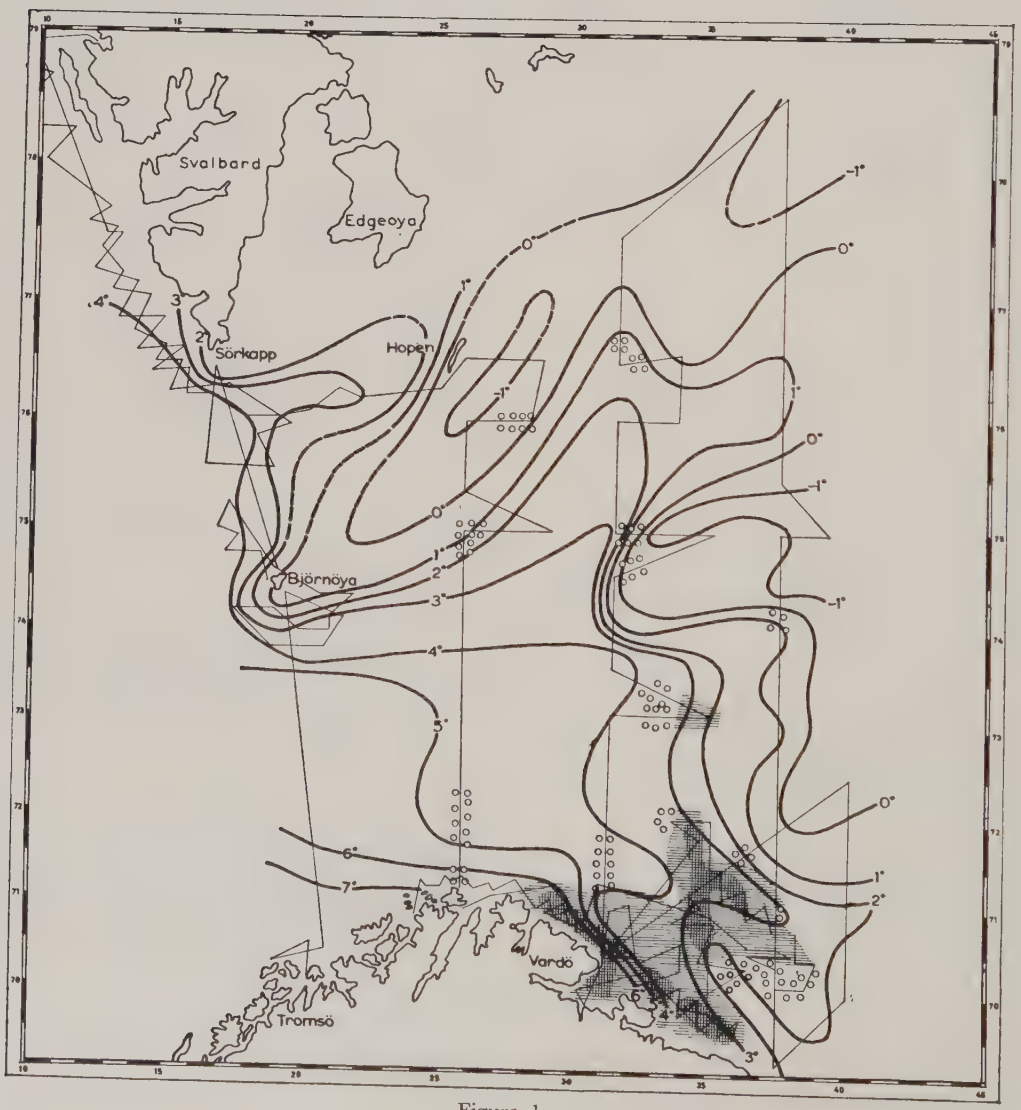

Figure 1.

When working her IGY programme of September/October 1958, the research vessel "G. O. Sars" at the same time made an echo-survey of the major part of the Barents Sea. Such echo-surveys are regularly undertaken in order to study the distribution of cod-haddock (which cannot be distinguished by the echo-sounder) in relation to hydrographical conditions.

The result of the echo-survey of September/October 1958 is given in Figure 1, showing the distribution of cod-haddock in the Polar Front area of the central and south-eastern Barents Sea. The fish concentration is illustrated by circles (lowest level) and two levels of hatching, and the heavy lines are isotherms representing water temperature at 150 m (or at bottom when more shallow) which was the depth of most of the fish. The thin lines indicate the different courses sailed by "G. O. Sars".

In the Svalbard area concentrations of cod-haddock were also registered, but in these localities we have too little experience of the fish behaviour to trust the validity of our echo-surveying technique, and registrations made in these waters are not included in the chart.

As seen from the figure the best concentrations were found within the warmer water tongues bending eastward, one close to the Finnmark-Murman coast and the other at some distance outside. The fish occurrences are easterly roughly limited by the 2°C isotherm. During recent years fishing in the eastern Barents Sea has been poor. This may have relation to the temperature conditions. Both Soviet and Norwegian observations have shown that the temperature of the south-eastern Barents Sea has generally been low since 1956.

The chart further indicates recordings in the Polar Front area above the Central Ridge and on the Hopen Banks, but in these localities the fish concentrations were low.

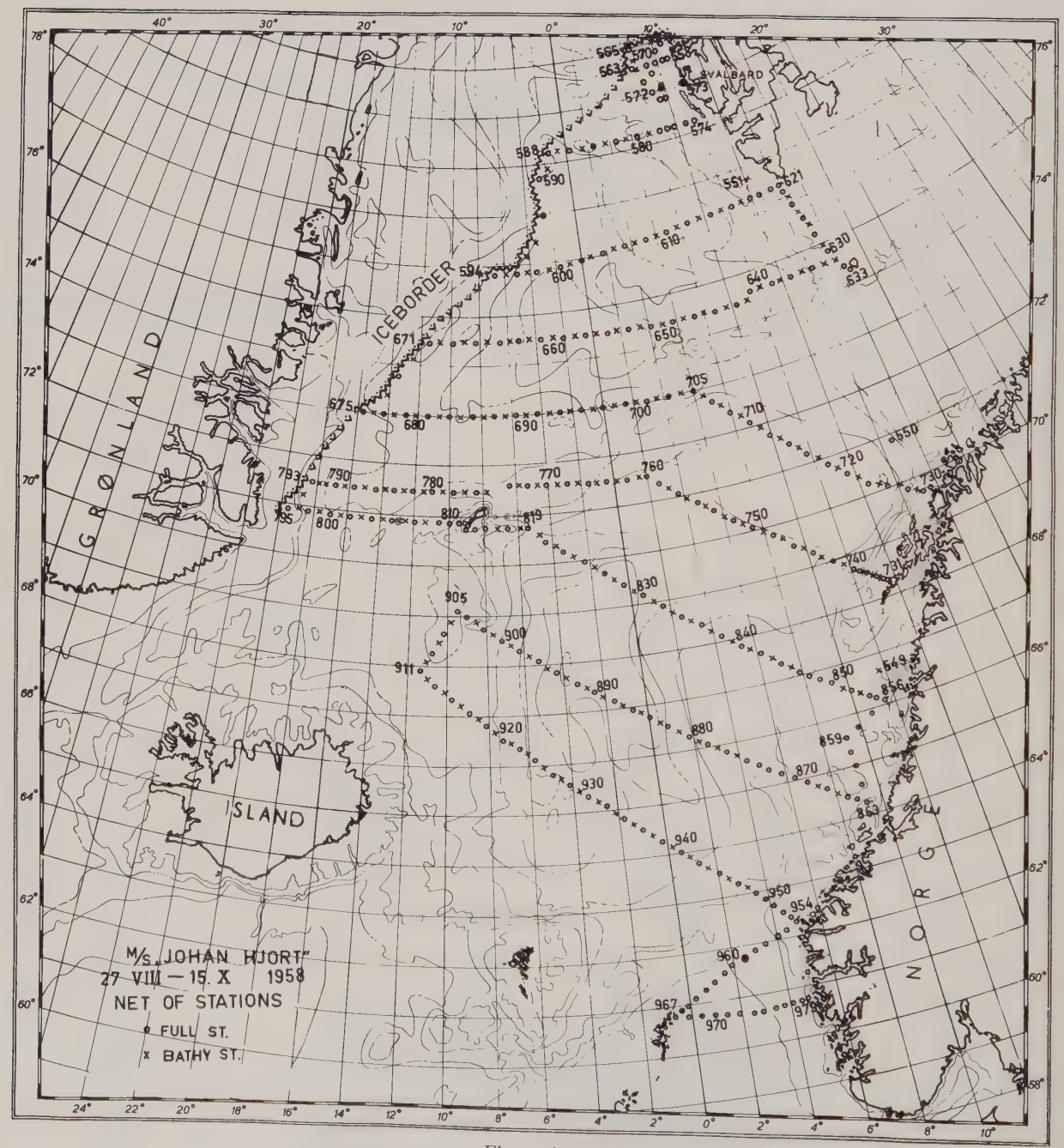
GRØNLAND
ISLAND
SVALBARD
NORGE
ICEBORDER
M/S „JOHAN HJORT"
27 VIII — 15. X 1958
NET OF STATIONS
FULL ST.
BATHY ST.

Figure 1.

Some Results of the Norwegian Hydrographical Investigations in the Norwegian Sea during the IGY

By

Jens Eggvin

During 1958 the Marine Institute of the Fisheries Directorate, Bergen, carried out two cruises in the Norwegian Sea as well as in the Barents Sea as a part of the Polar Front Survey Programme of the IGY. The two ships in commission were »G.O. Sars« and the new »Johan Hjort«. Figure 1 shows the network of stations from the autumn cruise in the Norwegian Sea. Small circles indicate full stations with observations at the standard depths from the surface to the bottom. A BT was operated at all stations. Crosses indicate stations

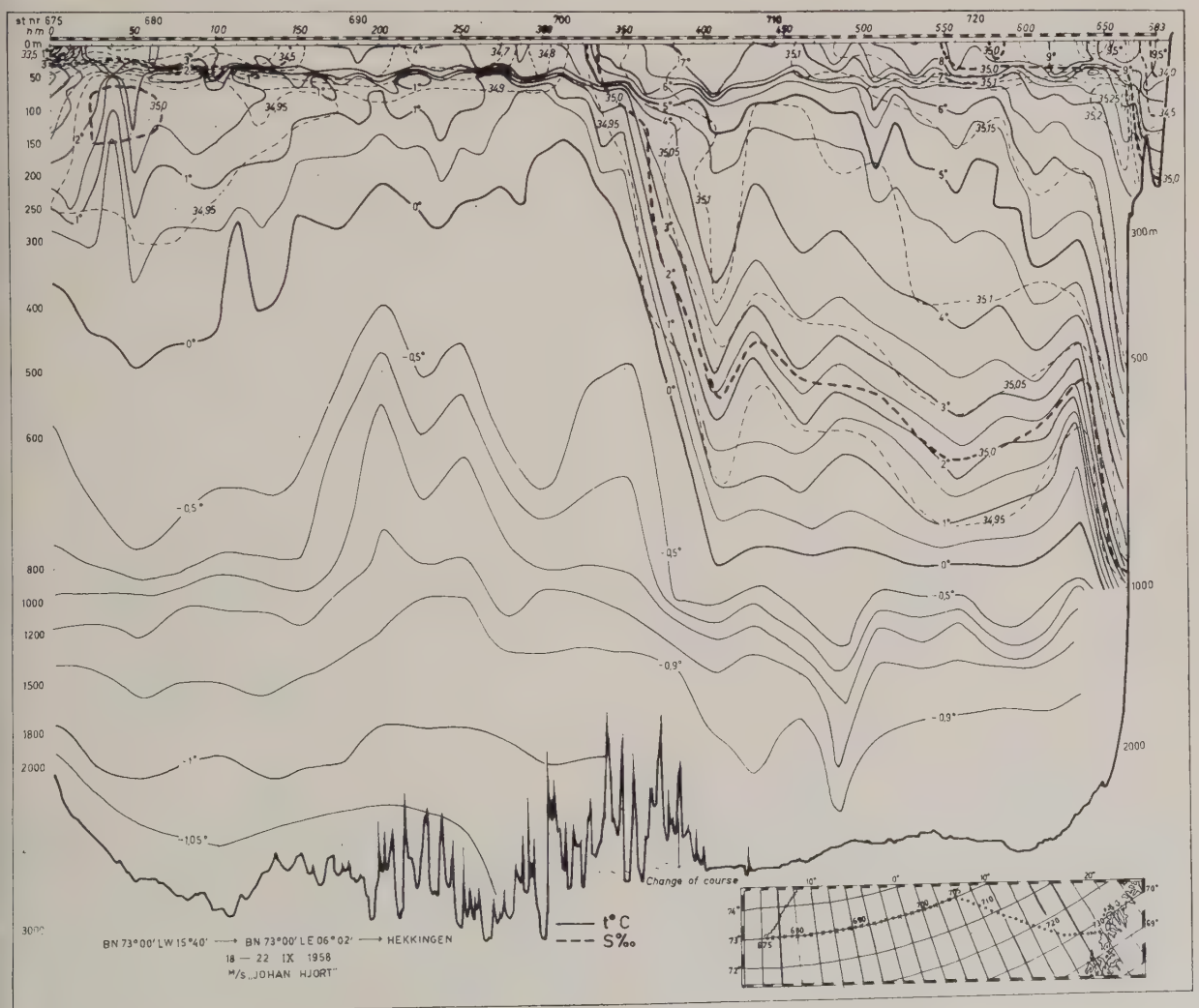

Figure 2.

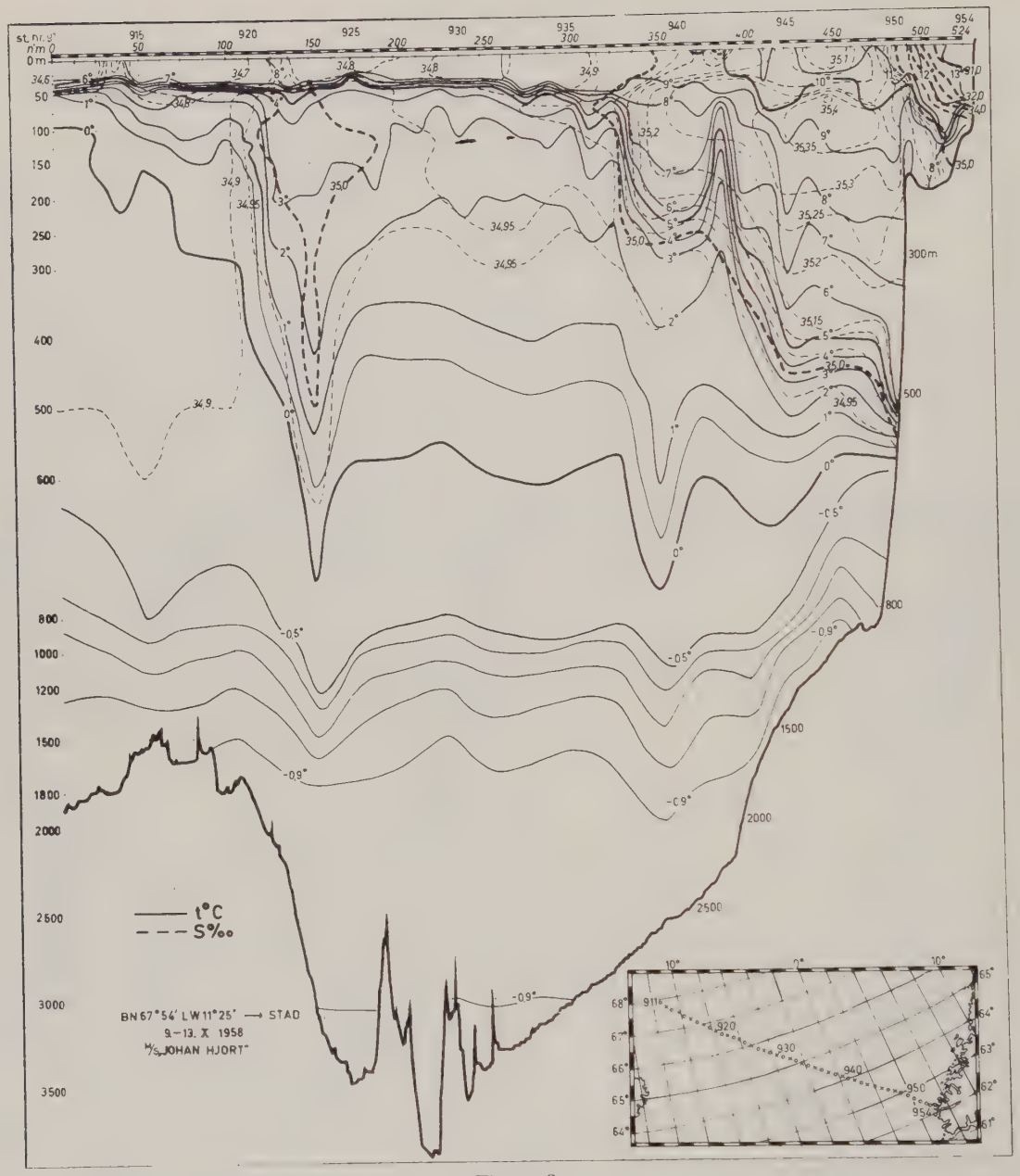

Figure 3.

where only a BT was operated. A similar network of stations was worked during the spring cruise. 719 full stations were taken and a BT was operated at the total number of stations, viz. 1,531. In all 17,600 samples were taken for salinity, oxygen, and phosphate analyses including those from the Barents Sea stations. Current measurements by means of serial and other current meters were carried out in some positions.

The temperature and salinity distributions along a section from the autumn cruises between the ice border off Greenland and Troms, Norway are shown in Figure 2. It was first along the latitude 73°N from 15°40′W to 06°02′E, and from there to Hekkingen on the Norwegian coast in latitude 69°49′N. The depth scale above 800 m is, for reasons of convenience, four times greater than from 800 m to the bottom. It will be seen that the composition of the water is quite different east and west of Mohn's Transverse

Ridge (from Jan Mayen towards Bear Island) with warmer and more saline water east of the ridge in the upper 1,000 m, except for the less saline coast water off the Norwegian coast in the upper strata. The 0°C isotherm is situated in about 800 m in the eastern part, and just outside the slope below 1,000 m, while in the western part it is found in the depths between 150 and 400 m. We see that Mohn's Transverse Ridge, which in the section rises to about 1,700 m, influences the flow of Atlantic water, even up to the surface. In 500 m the salinity and temperature at St. 707 is 35·03 ‰ and 3·05°C respectively compared with 34·92 ‰ and –0·51°C at St. 703 farther to the west. It will also be seen that the temperature of the bottom water is below –1°C west of the ridge and a little above –1°C east of it. The coldest area in the section is between 5°W and 5°E. This is in the central area just where the bottom water of the Norwegian Sea is formed.

In the western part of the section the salinity has a maximum above 34·95 ‰, between 50 and 250 m, and above 35 ‰ in the smaller area at Stations 677—680 at a depth of 75—150 m. This is water of Atlantic origin, which has turned to the west off West-Spitsbergen and is now penetrating to the south off the East Greenland Continental Platform. Station 675, at the ice border, shows that the water in the upper layer has been diluted to below 33 ‰. This is Polar water, carried to the south-west by the East Greenland Current. Just east of Mohn's Transverse Ridge there is a point where the Atlantic water reaches deeper than on either side. This is due to an anti-clockwise whirl, resulting in mixing with the colder and less saline water beneath.

Figure 3 shows the section from Stad towards the north-west to 67°54′N, 11°25′W carried out from the 9. to 13. October. The 0°C isotherm is found about a depth of 600 m, except in two areas where the temperature has a maximum and the 0° isotherm reaches down to 770 m. It will also be seen that the salinity has a maximum in these two areas at about 0°W and 6°W respectively. This is Atlantic water flowing to the south. It is more clearly seen by the help of a horizontal temperature and salinity chart and also by current charts.[1]) Below 2,500 m there is a slight rise in the temperature. It is anticipated that this is due to the subterranean heat of the earth.

It is seen that Atlantic water penetrates to greater depths in the northernmost of the two sections under consideration. This is especially the case just off the continental slope, where the thickness of the layer of Atlantic water is greatest. The Atlantic water in the Hekkingen section reaches to a depth of 900 m, but the corresponding depth in the Stad section is only 560 m. In correspondence herewith the temperature in the deep water off the slope is higher in the northernmost section, viz. 3·47°C and 1·24°C in 800 and 1,000 m respectively, compared with –0·67° and –0·93°C in the Stad section. (When the salinity in the deep water is a little higher in the northernmost section, this may be explained by the heavy mixing between Atlantic water on its way towards the north-east and the colder water beneath.)

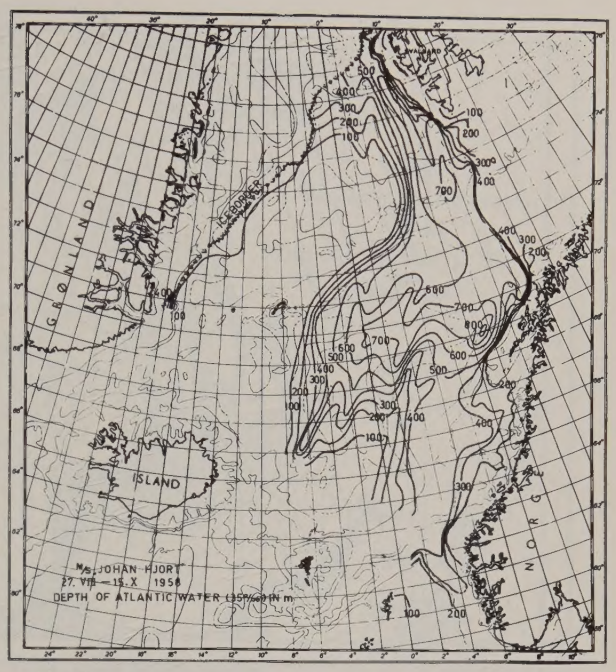

Figure 4.

The horizontal chart, Figure 4, shows the depth or thickness of Atlantic water with salinity $\geqq$ 35 ‰. In the southern part of the Norwegian Sea it will be seen that this water type is found in two areas separated by water from the East Iceland Arctic Current, which here penetrates towards the north-east. The maximum depth of Atlantic water in the section from Stad towards the north-west is 500 m. The thickness increases towards the north and reaches its maximum north and west of Lofoten, Vesterålen, and Troms, 700—925 m, especially off the slope. The thickness decreases from 700 m in the area west of Bear Island to less than 600 m off the northern part of West-Spitsbergen.

A longitudinal temperature section in the middle of the Norwegian Sea, between 65°35′N and 79°18′N, from the surface to the bottom is shown in Figure 5. It will be seen how the temperature increases, not only to the south, but also to the north of the main area, 74°—76°N, where according to Nansen the bottom water is formed. The temperature increase north of the

[1]) From 6°W the 0°C isotherm rises to a depth of 100 m at the ice-border.

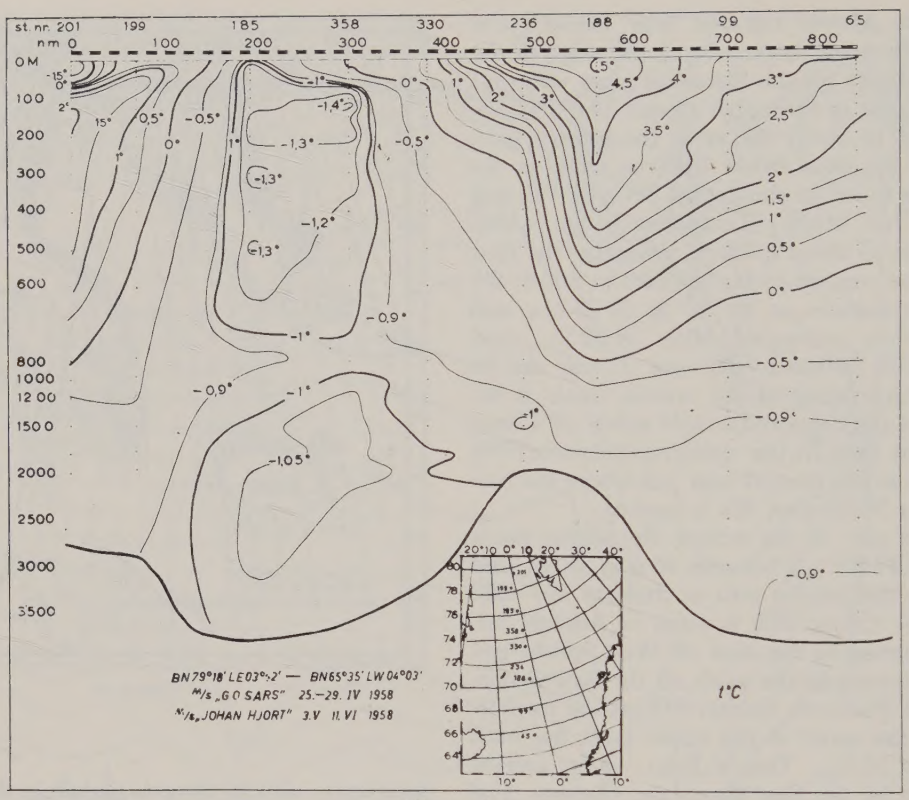

Figure 5.

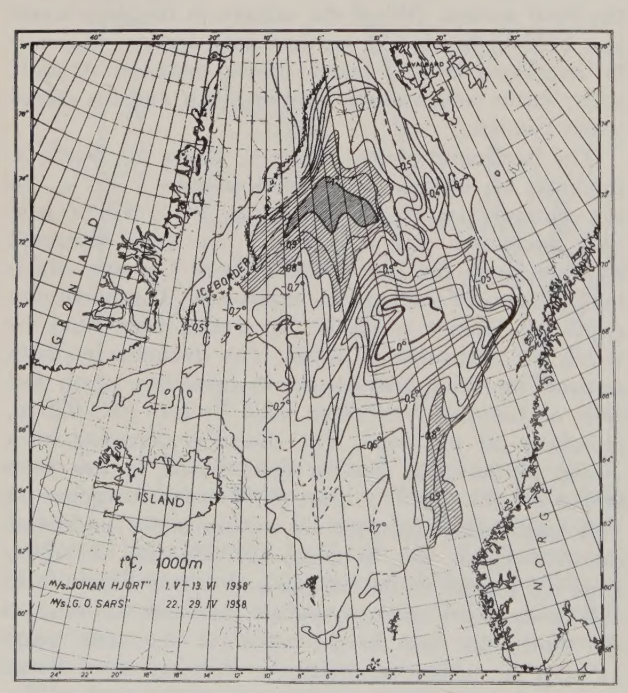

Figure 6.

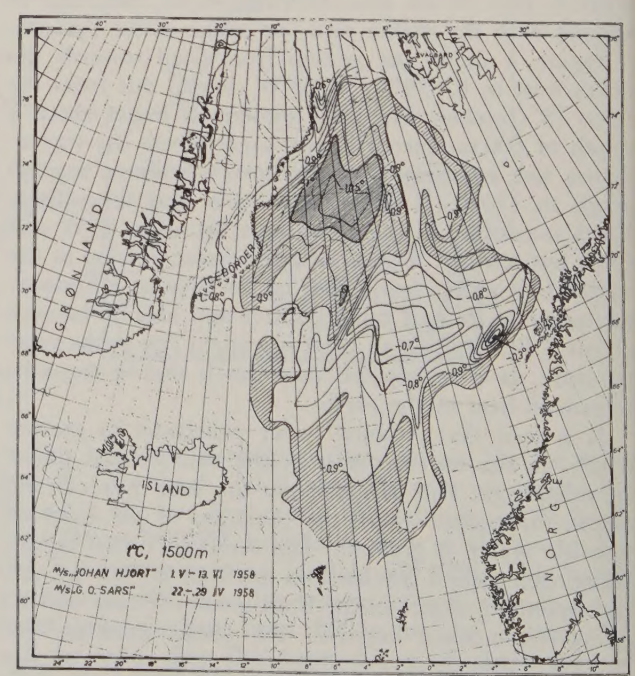

Figure 7.

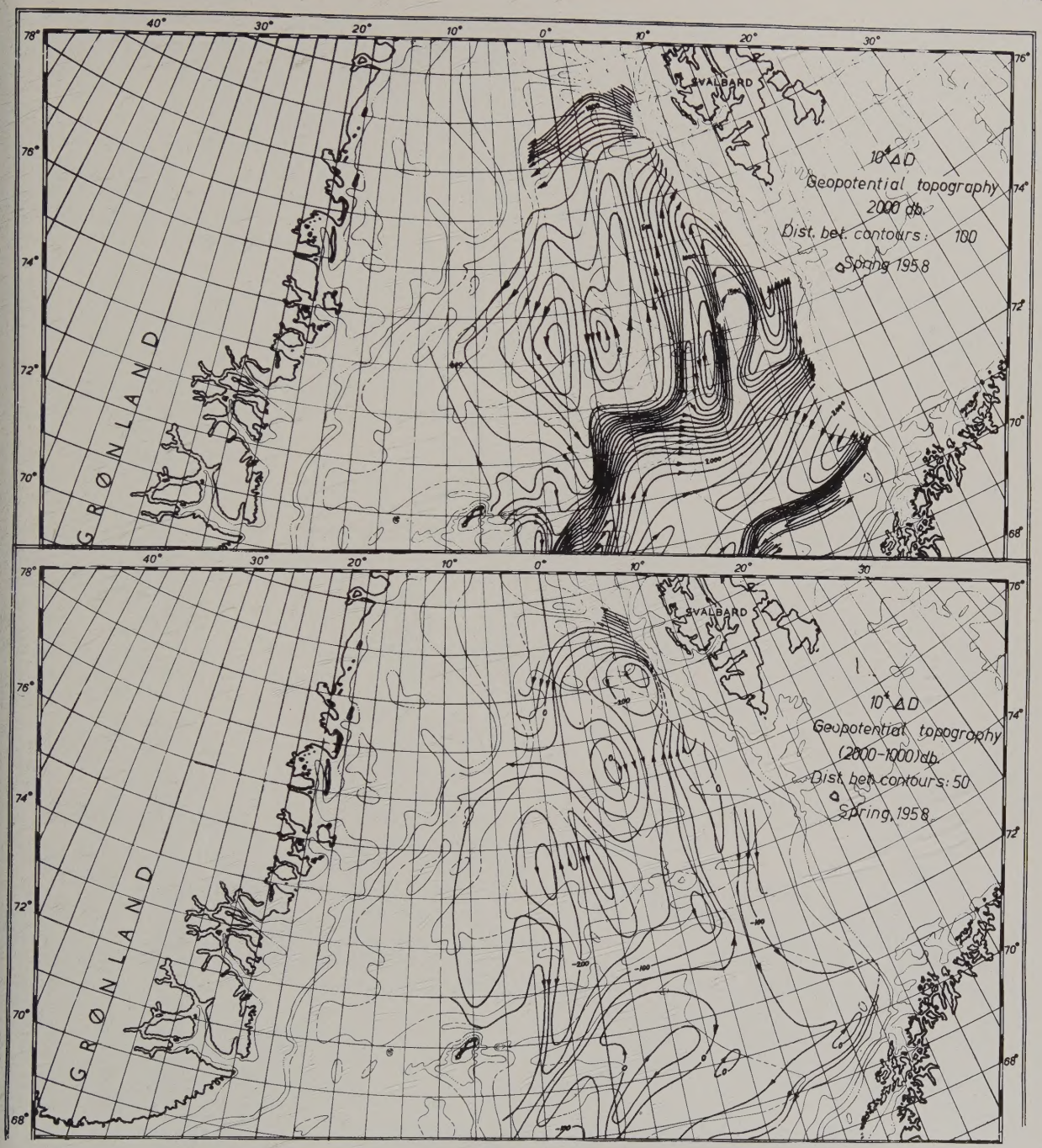

Figure 8.

rea mentioned takes place in the whole water column etween 100 m and the bottom.

This is demontrated more clearly by the horizontal emperature charts for 1,000 m and 1,500 m (Figs. 6 nd 7). The isotherms have been drawn for every 1/10° and 1/20°C respectively. We see that the temperature in the deep water varies relatively much, from 0·0 C to –1·0°C in 1,000 m and from –0·70°C to –1·05°C in 1,500 m depth. Both charts show that the temperature in the deep water increases from the main area (73°—

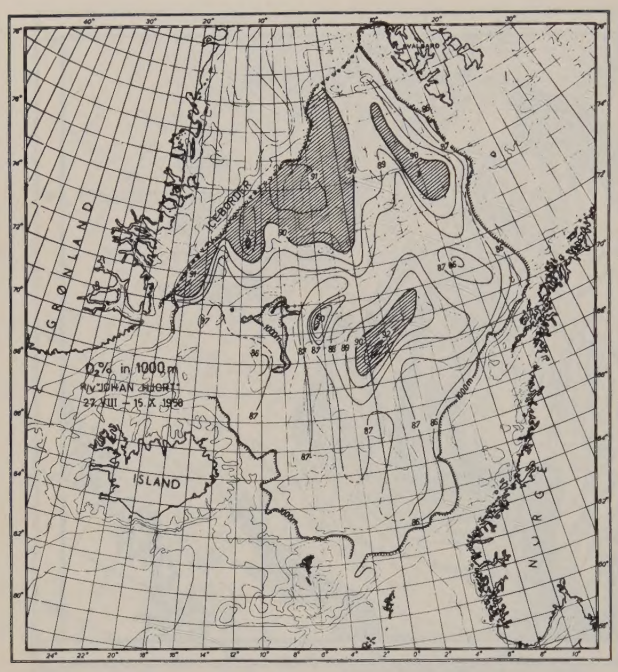

Figure 9.

76°N; 3°E—5°W) where bottom water is formed, towards the north, off West-Spitsbergen; from –1·10° to –0·40°C in 1,000 m and from –1·09° to –0·64°C in 1,500 m. In the deeper strata also there is a rise in temperature towards the north (Fig. 5).

The temperature increase is a result of mixing between the water type from the main area of bottom water formation and Atlantic water, which off West-Spitsbergen branches towards the west and north. In the northernmost part of the Norwegian Sea the temperature in the deep and bottom water is higher than farther south. The positive difference between the temperature of the bottom water of the Polar Sea and that of the greater part of the Norwegian Sea can therefore be explained without, as before, assuming a submarine ridge (about 1,300 m) between West-Spitsbergen and the north-eastern part of Greenland. This is in good agreement with the finding of Dr. Balakshin, USSR, who by investigation aboard ice-breakers, has shown that the sill depth between the Norwegian Sea and the Polar Sea exceeds 3,000 m. This will be only little modified by our new bathymetric chart of the Norwegian Sea, which shows that the sill depth is between 2,600 and 2,700 m at about 0° Long. off the northern part of West-Spitsbergen.

The character of the temperature distribution is different in the two basins south and north of Mohn's Ridge (Figs. 6 and 7). In the southern basin the temperature has a maximum in the central part against a minimum in the central part of the northern basin. As the salinity in the deep and bottom water varies extremely little, this temperature distribution has consequences for the currents in the deep water. We should expect a clockwise movement in the central area of the southern basin and an anti-clockwise movement in the northern basin. The chart of the current in 1,000 m depth (Fig. 8) shows that this is the case. It will be observed that just off the whole eastern continental slope of the Norwegian Sea from the southern part of West-Spitsbergen the temperature in the deep water is lower than further west (Figs. 6 and 7). This is in good agreement with our current chart of the deep water, showing water movements towards the south along the slope beneath the Norwegian Current.

The distribution of oxygen in 1,000 m (Fig. 9) shows that the percentage of O_2 is high over the whole Norwegian Sea with maxima in the central parts of the two basins mentioned and the minimum along the eastern continental slope.

Two charts of the approximate currents at the surface and 1,000 m depth relative to 2,000 m in the northern part of the Norwegian Sea are given in Figure 8. The upper chart shows the geopotential topography of the sea surface referred to the 2,000 db. surface. Contour lines are drawn for every dynamic cm ($10^2 \triangle D$). The lower chart shows the geopotential topography in 1,000 m depth referred to the 2,000 db. surface. Contour lines are drawn for every half dynamic cm. In the southern part of the Norwegian Sea Atlantic water in great quantities is turned to the north and north-west. From 70°—72°N and east of Jan Mayen it flows to the NNE and from about 0°Long. the current turns to the east along Mohn's Ridge. It branches and gets a more northerly direction. Between the two western branches is an anti-clockwise whirl which may be due to the bottom configuration. Another large part of the Atlantic water flows off the continental slope. Off the northern part of West-Spitsbergen Atlantic water flows to the west towards the continental slope of Greenland. In different sections we can trace this water as an intermediate current towards the south and south-west just off the slope. In the basin north-west of Mohn's Ridge (the Greenland Sea) the movement is anti-clockwise and in the basin north-east of the ridge the movement is clockwise. This is also the case in 1,000 m depth. Off the slope from north of Bear Island and off the Norwegian continental slope to 65°N the deep water flows to the south and south-west. This is also the case east of Jan Mayen. The speed of the current in 1,000 m relative to 2,000 m off the Norwegian continental slope between 62° and 68°N is 2—4 cm/sec. East of Jan Mayen and off Vesterålen the maximum speed of Atlantic water at the surface relative to 2,000 m is 18 and 16 cm/sec. respectively.